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THE DETERMINATION OF INCREMENT IN CUT-OVER STANDS OF WESTERN YELLOW PINE IN ARIZONA[1]

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INTRODUCTION

During the period 1909–1913 the Forest Service established a number of permanent sample plots in cut-over stands of western yellow pine (*Pinus ponderosa*) in Arizona and New Mexico. The purpose in so doing was twofold, first, to furnish a basis for studying the factors governing the establishment of reproduction, and, second, to supply data for determining the increment of stands left after cutting. It is with the latter subject that this report deals.[2]

When the plots were established it was assumed that the data obtained from them could be directly applied to extensive areas, on an acre basis. This method of determining increment gives correct results, provided that both the degree of stocking and distribution of diameter classes are the same on the sample plots as on the larger areas which they represent. In the case of even-aged stands such a relationship generally obtains and the acre-basis method of determining increment is therefore applicable to such stands. Moreover, relatively small plots may be used as a basis. But western yellow pine stands in the Southwest are uneven aged and, in addition, are very irregularly stocked; consequently it is almost impossible to select sample plots on which both the degree of stocking and the distribution of diameter classes are the same as on the larger areas. The difficulty could in a measure be overcome by laying out very extensive plots but this would defeat the very purpose of sample plots, in that they are supposed to furnish reliable data at a minimum expenditure of time and funds.

The plots as laid out comprised small plots for intensive studies, and somewhat larger plots to supplement the smaller intensive areas. It soon became evident, however, that even the largest of the plots that had been laid out were not representative of the larger units embraced in the national forest working circles, and that the data obtained from the plots must be used in some other than the usual manner to determine increment on such large areas. A method that would obtain the desired results accurately and economically and yet if possible make use of the plots already established was sought. The development of such a method is here described. This description is followed by analyses of some of the results obtained in its application. The period

[1] Received for publication June 29, 1925; issued March, 1926.

[2] The subject of reproduction has been treated as a separate matter by PEARSON, G. A. NATURAL REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST. U. S. Dept. Agr. Bul. 1105, 144 p., illus. 1923. The present report is based on sample plots established in cut-over stands in Arizona.

of observation is brief, it is true, but although the working value of the data obtained is thereby greatly limited, it is believed that the method itself has been well tested and that it can, with modifications be applied to all uneven-aged stands.

DESCRIPTION OF SAMPLE PLOTS

Of the sample plots established the small "intensive" plots ranged from 2 to 12 acres in size and the large "extensive" plots from 112 to 456 acres. For each of four of the extensive plots, designated as S 1, S 2, S 3, and S 4, two intensive plots were established. On a fifth extensive plot, S 5, constituting three silvicultural divisions, seven intensive plots were established to each division. These, because of their wide distribution, represented average conditions much better than the other intensive plots. All of the plots but two are on Forest Service cuttings and were established in the year that the areas were logged. Plots S 1 and S 2 are private cuttings, and were logged 15 years previous to establishment. Table I shows the years in which the plots were established and the acreages of the large and small plots, respectively.

TABLE I.—*Area of sample plots*

Plot designation	Year established	Extensive plots	Intensive plots	Percentage of area in extensive plots
		Acres	*Acres*	*Per cent*
S 1	1909	243	16.4	93.7
S 2	1909	135	11.9	91.9
S 3	1909	456	24.0	95.0
S 4	1909	304	16.0	95.0
S 5–I	1913	139	20.6	87.1
S 5–II	1913	151	16.9	89.9
S 5–III	1913	112	14.6	88.5

All of the plots lie within the Coconino and Tusayan National Forests. Two broad soil types are represented. That of plots S 1, S 2, S 3, and S 5 is the prevailing type, a stiff clay of basaltic origin mixed with basaltic rocks of various sizes, rich in mineral matter and having a high water-holding capacity. The topography of these plots is gently rolling and the altitude averages about 7,200 feet. The mean annual precipitation is around 23 inches. The other soil type, represented by plot S 4, is distinguished by the presence of a surface layer of black volcanic cinders varying from 1 inch to a foot or more in depth, the underlying soil being a stiff clay similar to that of the other plots. This plot also lies at a slightly lower altitude and probably receives 2 to 3 inches less precipitation than the others.

Because of differences in methods of cutting, the stands reserved on the plots vary somewhat. With one exception, however, the groups of young blackjacks [3] were retained intact. Other differences in the character of the stands which might have bearing on rate of increment are pointed out in the following paragraphs.

[3] "Blackjack" is a name locally applied to immature, dark-barked trees; the older, yellow-barked trees are called "yellow pine." Both are *Pinus ponderosa*, the distinction being entirely one of appearance, based upon age and rate of growth.

PLOT S 1, COCONINO NATIONAL FOREST

This plot adjoins the field headquarters of the Southwestern Experiment Station near Flagstaff, Ariz. Cutting was not done with any silvicultural object in view, but the character of the remaining stand is not radically different from that of stands now left on Forest Service cuttings, except that many of the seed trees are overmature and somewhat defective.[4] The young and middle-aged trees are fairly thrifty.

PLOT S 2, COCONINO NATIONAL FOREST

This plot lies about 1 mile east of S 1. Site conditions are practically the same, the soil, however, being deeper and more gravelly. A slightly higher percentage of overmature trees was retained than on S 1.

PLOT S 3, TUSAYAN NATIONAL FOREST

This plot is part of a Forest Service cutting situated about 5 miles west of S 1. The soil is less stony than that of plots S 1 and S 2, and consequently more impervious to water. Very few overmature or defective trees were retained. The present stand is fairly thrifty, but the growth of many of the younger trees is being retarded by mistletoe infection, which is also largely responsible for the mortality which has so far occurred.

PLOT S 4, COCONINO NATIONAL FOREST

Plot S 4, east of the San Francisco peaks, represents the cinder type of soil previously described. This plot is also a Forest Service cutting. Proportionally, many more mature trees were retained than on S 3 and almost as great a percentage of immature trees was reserved as on S 2. Most of the mature trees retained on S 4 are, however, very thrifty and their crowns are also well developed. In fact, most of the trees on the cinder soils have larger crowns than those on soils of purely basaltic origin. For this reason casual examination gives the impression that the trees on the cinder soils are much shorter. Measurements show, however, that they are almost as high as those growing on soils of basaltic origin.

PLOT S 5, COCONINO NATIONAL FOREST

This plot lies about 30 miles southeast of the Southwestern Forest Experiment Station. It was established for the purpose of comparing results under different methods of cutting and, as has been said, is divided into three silvicultural divisions, each one representing a different method. Site factors are practically the same for all divisions, and the soil is the same as on plots S 1, S 2, and S 3. A good many of the trees reserved are infected with mistletoe in spite of the fact that as many infected trees as possible were removed when the stand was cut over.

Since the character of the stand reserved depends largely on the method of cutting, it is well to point out the results of the three different methods. On Division I, which represents the group-selection method, only sufficient mature trees were reserved to insure regeneration of the stand. Most of these trees are thrifty and have

[4] The practice in Forest Service timber sales in the Southwest is to cut all overmature trees unless, in the absence of younger thrifty trees some of these must be left for seed. All of the thrifty immature trees and from two to four trees per acre of the thriftiest mature trees are retained.

well-developed crowns. On Division II, representing the scattered seed-tree method, aside from leaving three to four good seed trees to the acre, everything down to 11 inches in diameter was felled, including the larger trees within blackjack groups. On the shelterwood division (III) only a few of the older, and especially the most decadent trees were removed. Consequently, the mature trees reserved are considerably inferior to those reserved on the other divisions. Table II shows the distribution of trees by diameter groups on the various extensive plots.

TABLE II.—*Number of trees to the acre when plots were established*

[Data based on extensive plots]

Plot designation	Number of trees by diameter classes						Total over 11 inches		Proportion of blackjack to yellow pine	
	4 to 11 inches	12 to 20 inches	21 to 30 inches	31 to 40 inches	Over 40 inches	All diameters			Blackjack	Yellow pine
							No.	*Bd. ft.*	*Per ct.*	*Per ct.*
S 1	3.20	6.57	2.56	0.45	0.04	12.82	9.6	3,150	64.6	35.4
S 2	11.57	11.25	6.07	.38	.01	29.28	17.7	5,884	41.3	58.7
S 3	6.38	7.70	3.69	.32	.04	18.13	11.8	3,395	88.3	11.7
S 4	5.93	6.82	2.30	.27	.01	15.33	9.4	2,203	75.8	24.2
S 5-I	10.51	9.00	2.93	.20		22.64	12.1	2,940	80.8	19.2
S 5-II	4.66	1.80	1.80	.35	.03	8.64	4.0	1,990	60.5	39.5
S 5-III	10.53	9.19	3.97	.58	.01	24.28	13.8	4,700	71.7	28.3

METHOD OF DETERMINING VOLUME AND INCREMENT

On the intensive plots an individual record was kept of all trees over 3.6 inches d. b. h.[5] Diameters were measured to the nearest tenth of an inch with a diameter tape. Heights were measured to the nearest foot with a Forest Service standard hypsometer. On the extensive plots only the diameters were measured and calipers were used instead of a tape. No heights were taken. No individual tree record was kept.

It is evident that although both large and small plots give important data they do not supply the same kind. The data from the intensive plots give a reliable basis for determining the volume and increment of average trees in each diameter class, but because of the irregular stocking and distribution of diameter classes, these plots are too small to give representative stand data, as will be shown later under "Analysis of volume and increment of stands." It is obvious that the larger extensive plots supply better stand data and in this report they are used only for this purpose.

In making use of the data from the intensive plots, volume and increment of average trees were first determined, as a preliminary to applying these figures to the stand table furnished by the larger plots. The compilations deal with two distinct phases: First, determination of volume and increment of average trees, and, second, determination of volume and increment of stands.

DETERMINATION OF VOLUME AND INCREMENT OF AVERAGE TREES

In determining the volume and increment of average trees the average height and diameter of all trees in each diameter class are

[5] Diameter at breast height.

first obtained. The volumes corresponding to these average measurements are then taken from a graphic volume table, of which Figure 1 is an example. These averages form the basis for constructing volume and increment curves. The principle involved in such curve construction is revealed in Figure 2.

In determining the average volume and increment per tree to be used in computing the volume and increment of the stand, all trees were included. The volumes of blackjacks and yellow pines were, however, taken from separate tables and their respective differences in volume are therefore accounted for in the averages.

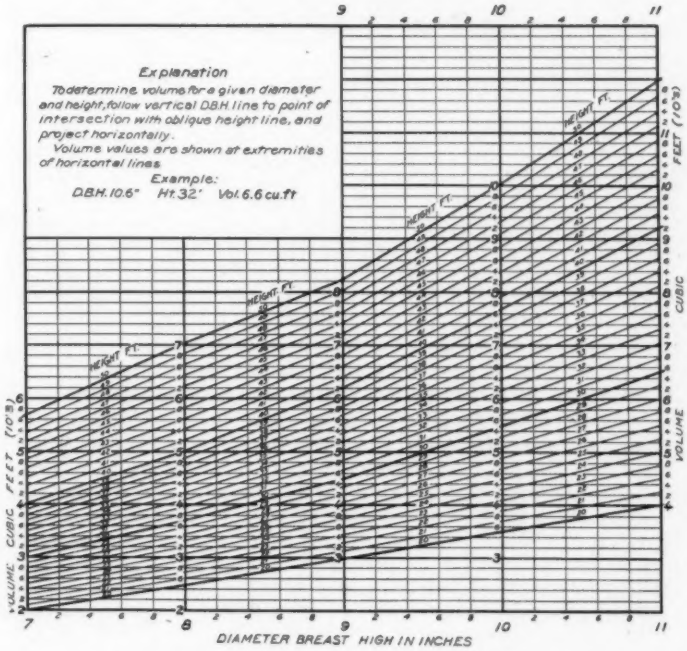

Explanation
To determine volume for a given diameter and height, follow vertical D.B.H. line to point of intersection with oblique height line, and project horizontally.
Volume values are shown at extremities of horizontal lines.
Example:
D.B.H. 10.6" Ht. 32' Vol. 6.6 cu. ft
HEIGHT FT.
VOLUME CUBIC FEET (100's)
CUBIC VOLUME FEET (100's)
DIAMETER BREAST HIGH IN INCHES

FIG. 1.—Example of alignment chart used for computing volumes of trees

VOLUME CURVES

Volume curves were constructed only for the original diameters—that is, for the diameters of trees at the time the plots were established. Instead of constructing new volume curves for each subsequent period, increment curves were made instead.

Since the trees on the intensive plots are tagged, it is possible to maintain a continuous record of growth of the same trees throughout any given period. The average increment of any diameter class is thus obtained by subtracting the original volume from the present volume. But these increment values are just as irregular as the volume values and are therefore plotted, and curves are drawn as for

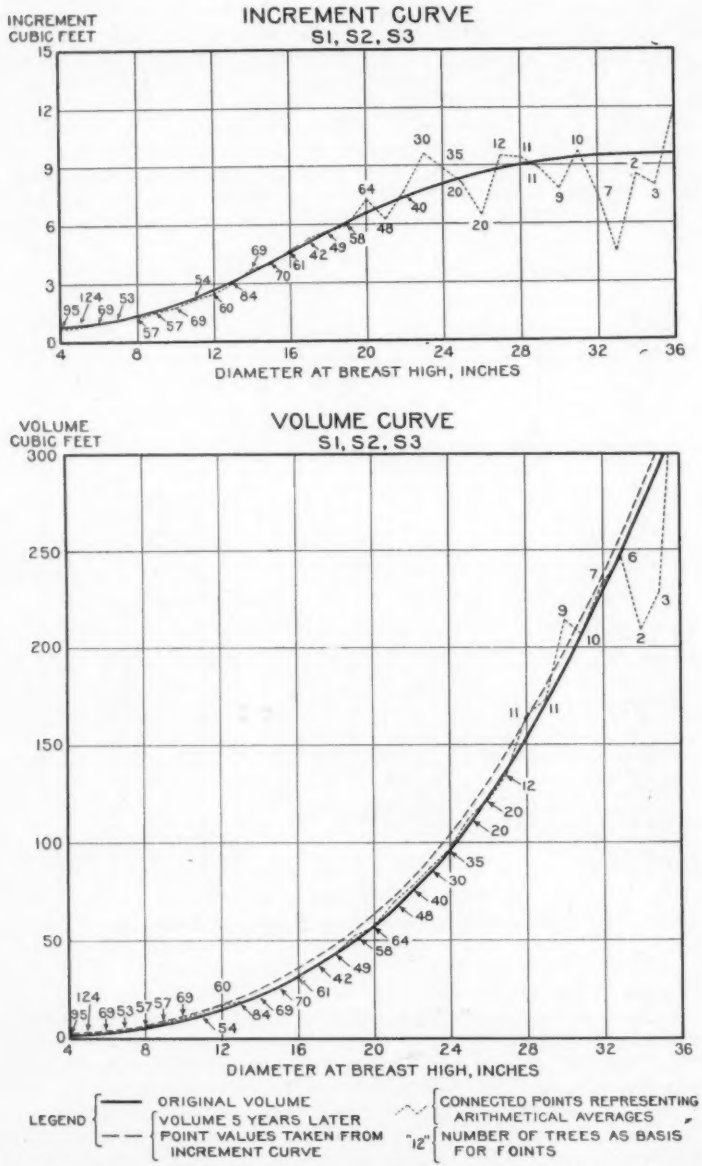


FIG. 2.—Volume and increment curves for average trees on plots S 1, S 2, and S 3; based on all trees of all intensive plots

volumes. Figure 3 shows the relation of this irregularity to the number of trees used as a basis. If these curved values are then added to the curved values representing the basic volumes, the com-

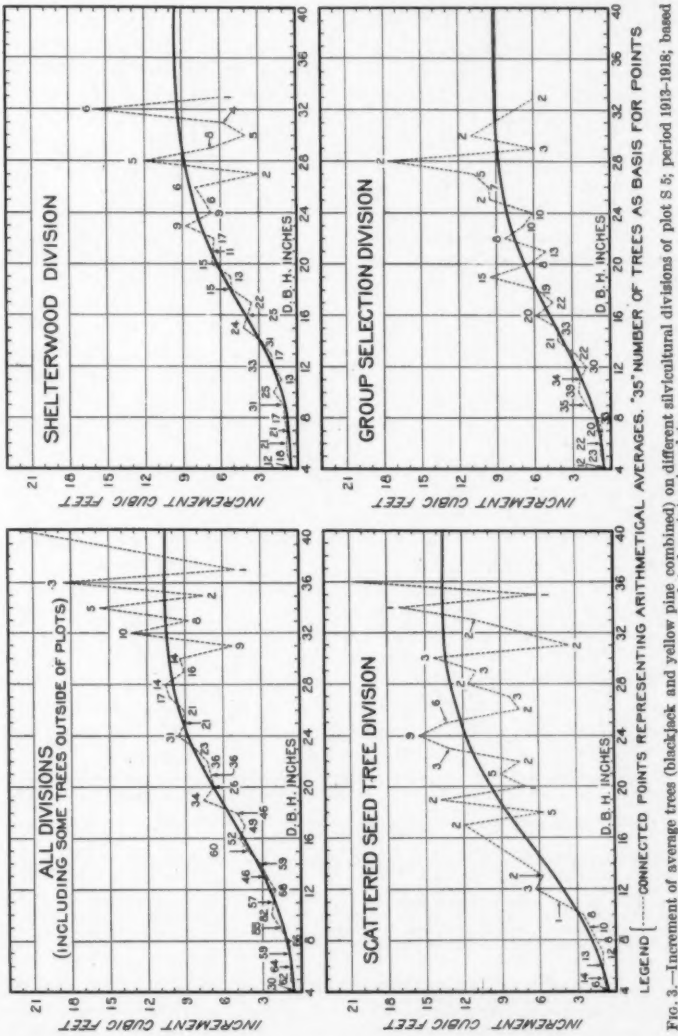

SHELTERWOOD DIVISION
GROUP SELECTION DIVISION
ALL DIVISIONS
(INCLUDING SOME TREES OUTSIDE OF PLOTS)
SCATTERED SEED TREE DIVISION
INCREMENT CUBIC FEET
D.B.H. INCHES
LEGEND [.....CONNECTED POINTS REPRESENTING ARITHMETICAL AVERAGES. "35" NUMBER OF TREES AS BASIS FOR POINTS

FIG. 3.—Increment of average trees (blackjack and yellow pine combined) on different silvicultural divisions of plot S 5; period 1913–1918; based on data from intensive plots

bined values will, when plotted, form a curve which represents the new volume (fig. 2).

It will be noted that the increment values are plotted on a larger scale than the volume values. This was done because it was considered essential to make closer interpolations for increment than for

basic volume. In other words, accurate data on rate rather than quantity of growth were sought. Moreover, an attempt to determine actual increment is not warranted at present because the volume tables themselves are based on the forms of trees in virgin stands rather than in cut-over stands.

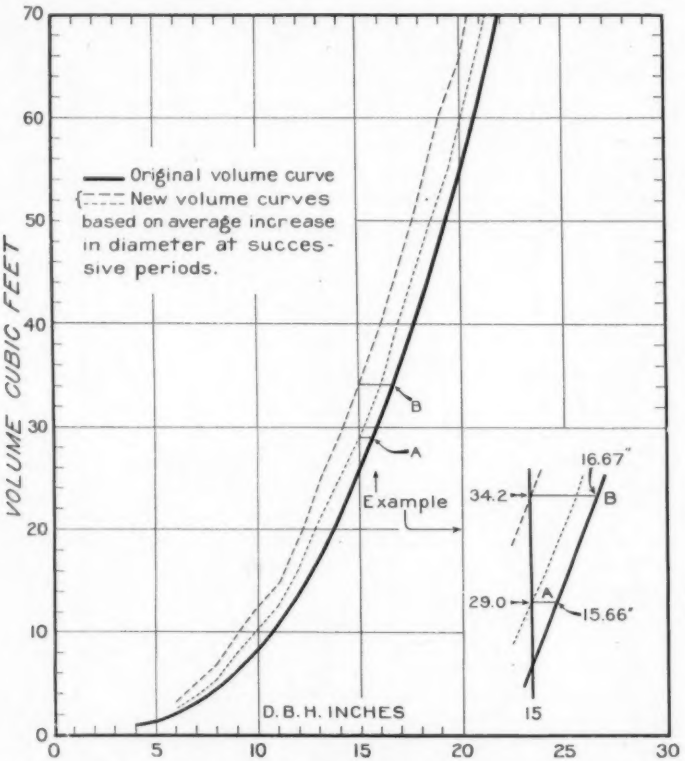


FIG. 4.—Illustrating method of computing volume growth of trees, by projection of diameter increase

The new curve is plotted by pointing off on original volume curve the new diameters, and projecting horizontally to the original diameters. The intersections of projected lines determine the new volume curve

Examples: A—Diameter of 15-inch trees has increased from 1909 to 1914 by 0.66 inches. New diameter, 15.66 inches, is pointed off on original volume curve; projection intersects former diameterat 29.0, new volume in cubic feet. B—Diameter increase of 15-inch trees (1909–1919) = 1.67 inches; new diameter = 16.67 inches; new volume = 34.2 cubic feet

As the original height measurements for plots S 1, S 2, S 3, and S 4, established in 1909, were unreliable, a different method of determining the increment of average trees was used in these cases. Instead of basing increment on both diameter and height, as was done for S 5, the average increase in diameter alone was used. The increase in volume was obtained by projecting the diameter values on a previously constructed volume curve as illustrated in Figure 4. The increment values were then plotted and curved as described above.

DETERMINATION OF VOLUME AND INCREMENT OF STAND

Having determined the volume and increment of the average tree in each diameter class, the volume and increment of the whole stand were readily obtained by applying these values to a stand table. In the present study the stand table is based on diameter measurements for all trees on the extensive plots. The original volume of the stand was obtained simply by multiplying the number of trees in each diameter class by the average volume per tree in each class as determined from the intensive plots. The sum of the total volumes of all classes gave the total volume of the stand.

In determining the increment of the stand a new method was used. Briefly, the steps involved in the new method are as follows:

The trees which have died during the period for which increment is to be determined are first eliminated from the stand table. The number of trees remaining in each diameter class is then multiplied by the average new volume per tree for each diameter class, as determined from the intensive plots. The sum of the total volumes of all classes minus the previous total volume gives the total increment of the stand with the volume of the dead trees eliminated.[6] To this the volume of new trees must be added.[7]

The difference between this method and that formerly used to determine the increment of stands is that by the former method all the trees on fairly extensive areas are remeasured at the end of each period. They are then reclassified into their new diameters and the volume computed in the same manner as described for obtaining the original volume of the stands. The growth of the same trees is not followed up and this method therefore affords no means of analyzing the increment data; it merely gives the total net increment of the stand on an acreage basis.

But even assuming that the former method gives reliable results for the extensive plots concerned, still there is no assurance that the results will apply to larger areas or areas differently stocked. By the new method, however, the increment of any forest unit may be determined, provided that an accurate stand table has been previously secured and that this table is periodically modified in accordance with the mortality which occurs in the various diameter classes.

[6] The following example for a single diameter class will make this clear:

Number of trees in d. b. h. class		Volume of average tree in cubic feet		Increment per tree, cubic feet
1911	1916	1911	1916	
49	47	29.0	31.1	2.1

If the number of trees in 1911 is multiplied by the average volume per tree, we have 49×29=1,421 cubic feet which is the original volume. During the 5-year period two trees have died. The volume in 1916 is obtained by multiplying the number of surviving trees by the new volume of the average tree of this diameter, namely, 47×31.1=1,461.7 cubic feet. The increment is the difference between these two totals, or 40.7 cubic feet.

Another method would be to determine first the increment of the average tree, which is 2.1 cubic feet, and multiply the number of trees in 1916 by this figure, obtaining 98.7 cubic feet as a gross increment. From this amount the volume of dead trees (29×2=58 cubic feet) must still be subtracted, thus involving an extra calculation which the above method avoids.

[7] "New" trees are those which were below measurable or merchantable size when the plots were first measured, namely, below 3.6 inches d. b. h. where cubic volumes are considered, and below 12 inches d. b. h. where board foot volumes are concerned.

The principal precaution that must be taken in the application of this method is that reliable mortality data be obtained.

The advantage of the method advocated is that the increment for one or more diameter classes may be determined separately—information obviously valuable as a guide to the future management of stands.

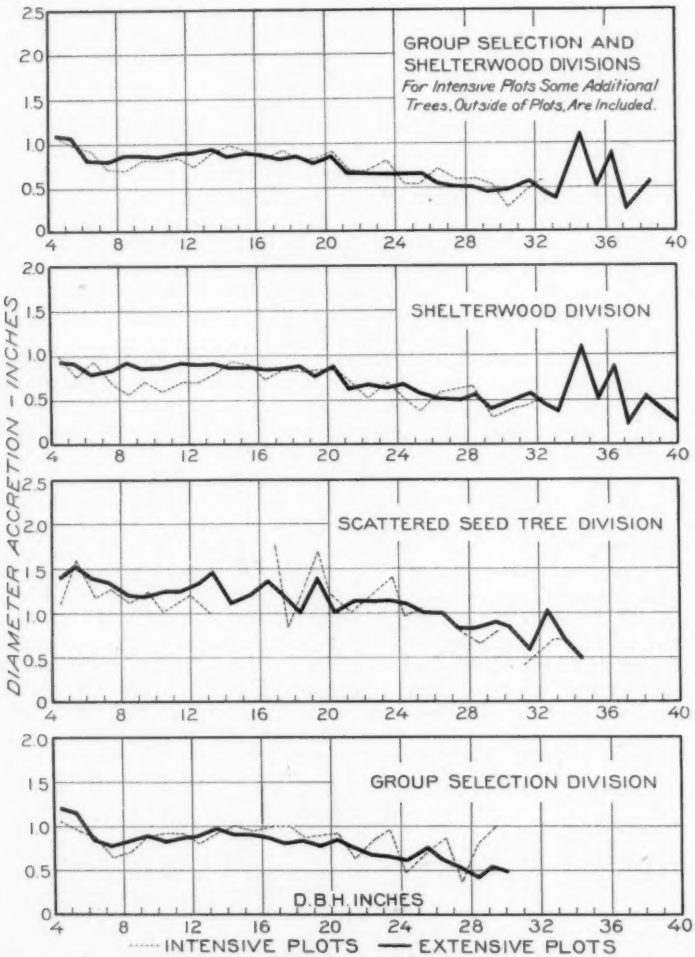


FIG. 5.—Diameter accretion of all trees (blackjack and yellow pine combined) on extensive and intensive plots; period of 1913–1918; based on data from plot 8 5

In the present computation this method revealed the reasons for differences in increment which would otherwise not have been detected.

Objection to this method may be made on the score that the increment of average trees will not be correctly represented unless all of the trees on extensive areas are periodically measured. Investiga-

tion shows, however, that a relatively small number of trees gives practically the same degree of accuracy as a large number. The results of an investigation along this line may well be presented in detail.

COMPARISON OF GROWTH OF TREES ON EXTENSIVE AND INTENSIVE PLOTS

In order to determine the relationship between large and limited numbers of tree measurements, a study was made of the growth of trees on extensive and intensive sample plots of S 5. The comparison of growth had to be based on diameter increase only, because no heights were taken on the extensive plots. The diameter values were, however, converted into their corresponding volumes in order to facilitate the construction of curves. Basal areas might have been used instead, but the conversion of diameter values into corresponding volumes by the method of projection (fig. 4) gives results of the same relative value for both intensive and extensive plots, because the same constants (volume curve values) are applied in the conversion of diameter measurements. It is assumed that comparison on the basis of diameter growth alone is a fair one because the sites represented by the intensive plots are typical of the extensive plots, and therefore height growth should be proportional to diameter growth in either case.

The compilation was made as follows: The trees were classified by diameter classes and the average of each class determined. The increase in volume was then determined by the method of projection mentioned above.

The average diameter and accretion of average trees for extensive and intensive plots on the different silvicultural divisions of plot S 5 are shown graphically in Figure 5. It will be noted that there is no consistent relationship between the accretion of trees on extensive and intensive plots; in some diameter classes growth on the intensive plots was greater and in other classes less than on the extensive plots. The values should therefore be analyzed on the basis of diameter groups rather than by single diameter classes. Results compiled on this basis are given in Table III.

TABLE III.—*Diameter accretion of trees on extensive and intensive sample plots, compared on the basis of diameter groups, period, 1913–1918*

Method of cutting and diameter class	Average accretion, 1913–1918 (inches)		Difference [a] in accretion (inches)		Number of trees as basis	
	Extensive	Intensive	Extensive	Intensive	Extensive	Intensive
Group selection division:						
4 to 11	0.926	0.870	0.056		1,180	242
12 to 20	.868	.934		0.066	1,070	194
21 to 30	.602	.681		.079	280	59
Scattered seed-tree division:						
4 to 11	1.320	1.236	.084		520	67
12 to 20	1.230	1.294		.064	207	16
21 to 30	.994	1.001		.007	237	34
Shelterwood division:						
4 to 11	.872	.784	.088		970	153
12 to 20	.864	.824	.040		920	186
21 to 30	.560	.537	.023		332	76
Group selection and shelterwood divisions combined: [b]						
4 to 11	.902	.859	.043		2,150	440
12 to 20	.863	.874		.011	1,990	415
21 to 30	.584	.607		.023	612	178

[a] Difference is indicated with reference to plots on which the accretion of trees was greatest.
[b] Intensive plots include some additional trees outside of plot boundaries.

Table III shows some inconsistencies, but in no case is the difference between growth on extensive and intensive plots very great. On the group selection and scattered seed tree divisions the growth of trees above 11 inches in diameter was slightly greater on the intensive plots. Below 11 inches the growth was a little less on the intensive plots. On the shelterwood division the growth averaged lowest for trees on the intensive plots, including all diameter groups. In order to have a large number of trees as a basis for the intensive plots, the values for the group selection and shelterwood areas were combined. A comparison of growth for these combined areas shows the same relationship as for the group selection division considered alone, although differences are not so great. On none of the divisions, however, are the differences between growth of trees on exten-

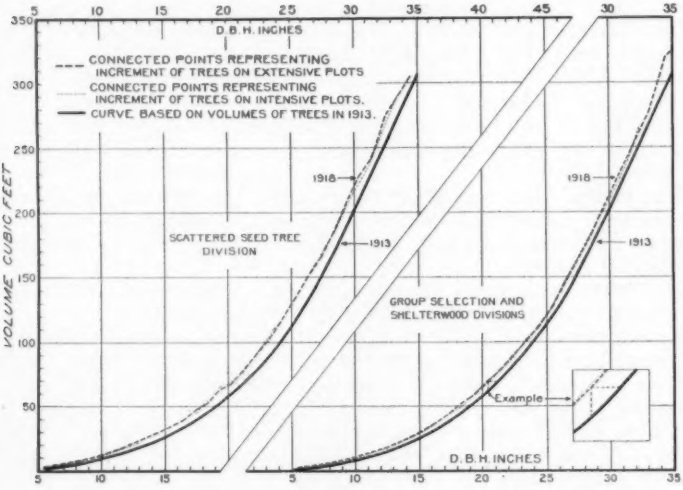

D.B.H. INCHES
CONNECTED POINTS REPRESENTING INCREMENT OF TREES ON EXTENSIVE PLOTS
CONNECTED POINTS REPRESENTING INCREMENT OF TREES ON INTENSIVE PLOTS.
CURVE BASED ON VOLUMES OF TREES IN 1913.
VOLUME CUBIC FEET
1918
1913
SCATTERED SEED TREE DIVISION
GROUP SELECTION AND SHELTERWOOD DIVISIONS
Example
D.B.H. INCHES

FIG. 6.—Increment of trees on extensive and intensive sample plots; period of 1913–1918; based on data from S 5

sive and intensive plots great enough to disqualify the use of a limited number of trees as a basis for determining the average growth of all trees in the stand. When the diameter values are converted into corresponding volume values and curved, the results correspond still more closely. This relationship is shown in Figure 6. It will be noted that the broken lines representing the connected points of increased volumes of trees on the extensive plots very nearly form curves in themselves. But the values representing the increased volume of trees on the intensive plots are also sufficiently consistent so that correct curves can be drawn in spite of the limited data.

It is an interesting fact that the points representing the increased volumes of trees for the scattered seed tree division approach so nearly the form of a curve in spite of the relatively limited number of trees used as a basis. However, the trees reserved on this division had better and more uniform crown development than the average

trees reserved in the different diameter classes on the other divisions. Consequently, fewer variables are involved and therefore a curve of growth can be constructed on the basis of fewer trees.

MODIFIED METHOD OF COLLECTING FIELD DATA

In the present report intensive plots were used as a basis for determining the increment of average trees and extensive plots as a basis for a stand table. This does not imply that the same bases should be used in future applications of the method. In fact, intensive plots should be dispensed with altogether and instead trees well distributed throughout the stand should be selected for measurement. Approximately the same number of trees should be selected in each diameter class, because this makes it easier to balance values in the construction of curves. The trees should, however, be selected with reference to the proportional differences in age, vigor, and crown classes as they actually occur in the stand. This information will be obtained at the time that the stand data are collected.

Instead of basing the stand data on regular extensive plots it will probably be better to run strips, thereby covering a greater variety of conditions and at the same time keeping the area basis down to a minimum. These plots or strips, as the case may be, should, however, be permanent, for they are to be used not only as a basis for the present stand table, but also as a basis for determining the mortality which occurs from time to time in the various diameter classes in order to correct the stand table. To obtain this information it is further necessary to know the original diameter class to which each dead tree belonged, and obviously this can not be readily determined unless the trees are tagged at the time the plots are established. All trees on the extensive plots or strips should therefore be tagged. This also applies to the new trees entering the stand.

The question may be raised whether, since all trees on the extensive plots are to be tagged, it would not be advisable to recaliper all of them periodically, just as has been done in the past. The answer is that this probably would not add to the accuracy of the results. In fact, as will be noted from Table III, the difference between diameter growth of a large and a smaller number of trees is not very great. When the data are curved the results correspond very closely. It is therefore evident that the accurate measurement of a limited number of trees gives entirely reliable results.

APPLICATION OF METHOD TO EVEN-AGED STANDS

Although this method of determining the increment of stands was developed specifically for western yellow pine, it should be equally applicable to uneven-aged stands of any species. It might, indeed, be advisable to apply the method to even-aged stands as well, because many stands in this country, although even aged, are very irregularly stocked. This condition applies especially to the present forests in which numerous openings occur as the result of fire, insect depredations, and other agencies. It is extremely doubtful whether sample plots can be selected which will furnish a reliable index of increment for such stands as a whole. Moreover, site factors are apt to vary within comparatively short distances and any attempt

to define the limits of each site involved is subject to great error. Many of our even-aged stands will also be managed as selection forests. They will then be essentially uneven aged, and consequently similar to any natural uneven-aged forest. The determination of their increment should, therefore, be made by the method best suited for uneven-aged stands.

It is believed that the general use of the sample plot method of determining increment on an acre basis and regardless of the character of stands has evolved from the adoption of European methods in preference to developing methods of our own applicable to our own stands. In Europe most of the forests are very intensively managed, the stands are kept uniformly stocked, and site qualities are carefully segregated. Under such conditions representative sample plots may be selected with ease. In this country it will be many years before stands are so managed, if they ever are, and our methods should accordingly be worked out with this difference in mind.

COMPARISON OF RESULTS OBTAINED BY THE TWO METHODS

Table IV shows total net increment for the various plots as compiled by both of the methods previously described. These are indicated as method A (the new method) and method B (the old method). The figures cited for method A are the same as those shown later in a corresponding section of Table X, except that the increment due to new trees has been added, so that comparison with the results by method B can be made.[8] The reason for the discrepancies that will be noted between the two methods can best be explained by again referring to the factors involved in each method.

TABLE IV.—*Comparison of increment determined by two different methods*

Plot designation	Annual increment per acre [a]			
	Method A	Method B	Difference	
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Per cent*
S 1	10.00	8.04	−1.96	−19.6
S 2	27.02	31.28	+4.26	+15.8
S 3	11.93	16.80	+4.87	+40.8
S 4	9.55	12.43	+2.88	+30.2
S 5–I	10.15	10.37	+0.22	+2.2
S 5–II	3.30	4.36	+1.06	+32.1
S 5–III	9.98	13.40	+3.42	+34.3

[a] For plots S 1, S 2, S 3, and S 4, increment is the average for 10 years. For plot S 5 increment is the average for 5 years.

The higher increment obtained by method B is probably largely due to the fact that the same volumes of average trees were used to determine the volumes of the stand for both original and subsequent periods.

Even if new volumes of trees based on the present heights had been prepared, these might still have given erroneous results, because different trees would be used as a basis for each diameter class in

[8] A further exception to be noted is that on plot S 1 a number of trees which were girdled were excluded in the compilation by method B. The increment obtained by method A was therefore reduced proportionally.

each period—that is, since the trees vary greatly in height the average height for a given diameter class in one period might be inconsistently greater or even be less than the average height of trees in that class in another period. Another possible source of error in method B is that the diameter classes are based on even instead of fractional parts of an inch. Errors on this account would be especially effective where trees of large diameters are concerned.

The results obtained by method A are considered the more reliable. But for the purpose merely of showing relative increment on different plots, the two methods are equally valuable.

ANALYSIS OF RESULTS

It has been previously pointed out that the method advocated in this report, besides being more practicable in determining the increment of stands, reveals facts which could not be detected by the method formerly used. In the following pages are given some of the facts so deduced. These conclusions should, however, be considered as tentative, owing to the brief period of observation and, in some instances, the rather meager data obtained.

ANALYSIS OF VOLUME AND INCREMENT OF AVERAGE TREES

The volume and increment of average trees was determined for each plot and also for several plots combined.[9] In Figures 7 and 8 the increment curves are plotted so as to show the relationship between increment and the character of the stand retained after cutting.

In accounting for the differences in increment it is difficult to isolate all of the factors which may be involved. The principal factors, however, are age and vigor of trees. Thus the increment of trees on S 1 and on S 2 is fairly similar. but slightly better growth obtains on S 1, because on the whole the trees retained on this plot were thriftier, On S 3, in spite of the fact that in the lower diameter classes the increment was relatively low, owing to mistletoe infection, the average growth of trees was better than on either S 1 or S 2. This is because most of the trees reserved in the higher diameter classes were thrifty blackjacks. It should be recalled that S 1 and S 2 represent private cuttings, whereas S 3 represents a Forest Service cutting. On S 4 the average growth of trees is still better than on any of the preceding plots, especially in the case of yellow pines which have maintained a very rapid rate of growth. But S 4 also represents a Forest Service cutting and most of the large trees retained for seed have fairly long and well-developed crowns. The younger blackjacks are in unthinned groups, as is the case on the other plots, and the growth of these trees was, therefore, not affected by the removal of the older trees in the stand.

The effect of the different methods of cutting on plot S 5 is strikingly revealed in Figure 8. The growth of trees bears a direct relationship to the degree of cutting, and is also partly affected by the quality and character of trees reserved. Thus, the excellent growth of trees on Division II is probably largely due to the fact that only the very best trees were reserved. The average growth of trees on Division

[9] Because the original height measurements were inaccurate on plots S 1, S 2, S 3, and S 4, the increment of trees on these plots is based on the second 5-year period only.

I is, however, not much greater than that on Division III, although cutting on the latter division was considerably lighter. In this case site must be considered and judging from the superior growth of the

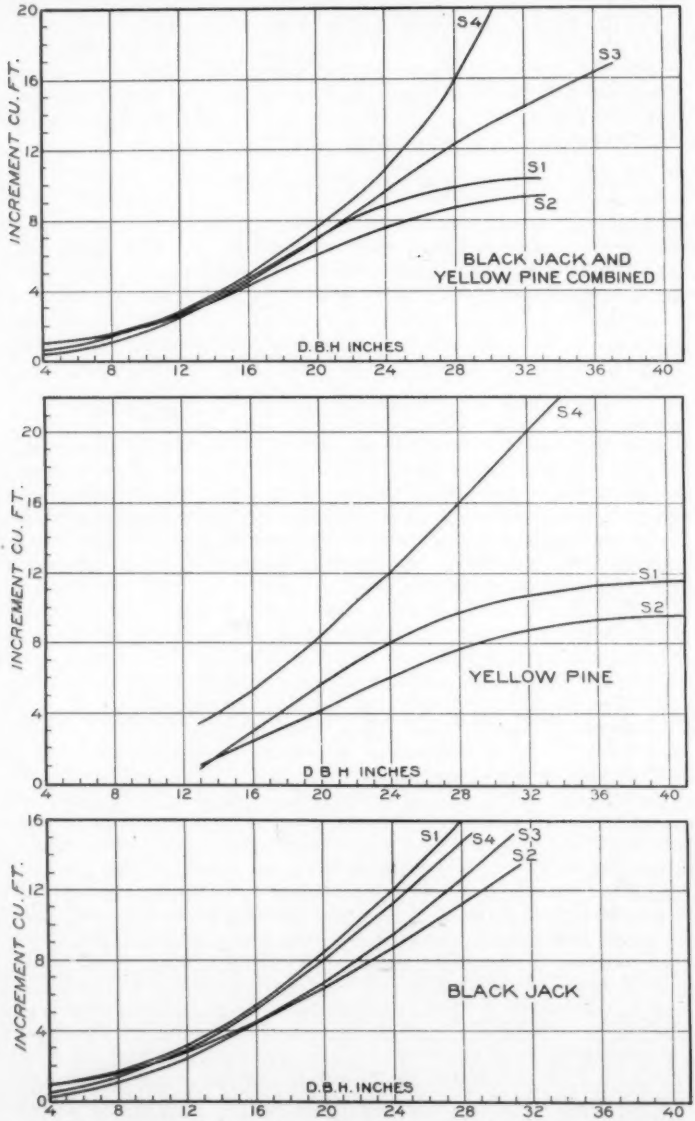


FIG. 7.—Increment of average trees in relation to character of stand left after cutting on different soil types, S 1, S 2, and S 3 represent basalt soils on which 641 cubic feet, 1,197 cubic feet, and 732 cubic feet per acre, respectively, were retained after cutting. S 4 is a cinder area on which 503 cubic feet was retained. Basis, intensive plots for 1914–1919 (insufficient data for yellow pine S 3)

mature yellow pines on Division III, this division appears to be the better site of the two. The growth of blackjack does not give the same indication of superiority of site because blackjack groups are denser on Division III than on Division I.

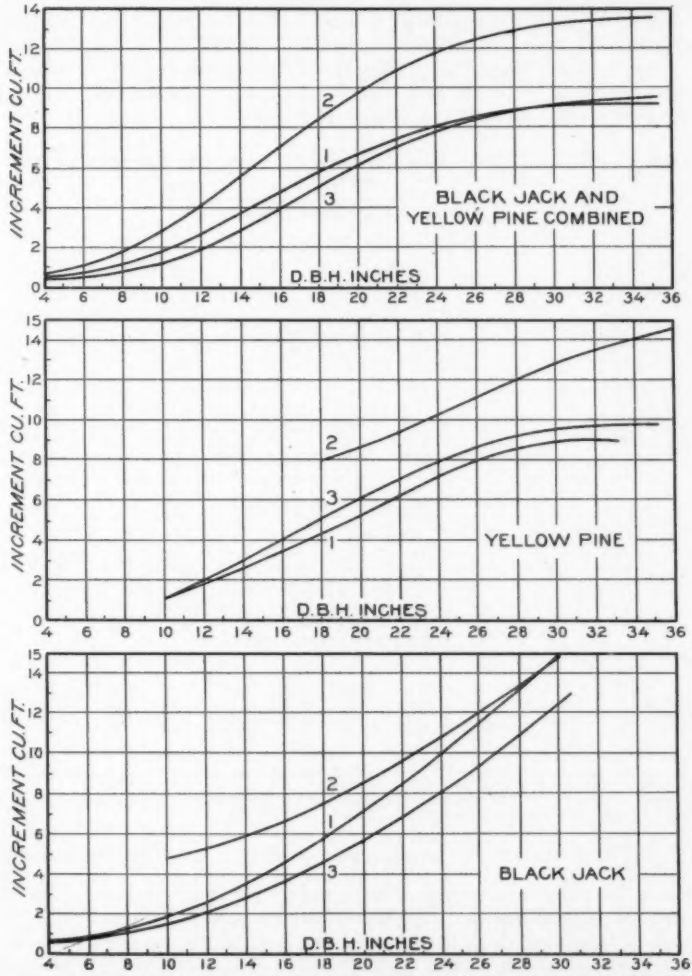


FIG. 8.—Increment of average trees in relation to character of stand left under different methods of cutting. On the group-selection division (1) 640 cubic feet per acre was retained; on the scattered-seed-tree division (2), 384 cubic feet; on the shelterwood division (3), 970 cubic feet. Basis, intensive plots of S 5 for 1913–1918

A fact of silvicultural importance revealed by the curves in Figures 7 and 8 is the continuous increase in increment maintained by blackjacks, including those in the higher diameter classes. Yellow pines, on the other hand, are seen to fall off in growth, except on plot S 4

and Division II of plot S 5. The yellow pines on these two plots are, however, thrifty trees with well-developed crowns. This shows the importance of considering vigor and size of crown in selecting trees to be reserved for seed; the age of the tree is of comparatively less importance.

Table V is a summation of the curved volume and increment values of all trees, by diameter groups. Since the average volumes of trees in each diameter group are different on each plot the relations between volume and increment vary accordingly and are therefore shown also on a percentage basis.

TABLE V.—*Volume, increment, and increment per cent of average trees by diameter groups* [a]

[Based on data from intensive plots]

VOLUME IN CUBIC FEET

Diameter class	S 1	S 2	S 3	S 4	S 5			
					I	II	III	All divisions [b]
4 to 11	32	32	43	35	37	37	40	38
12 to 20	293	304	294	285	280	311	299	294
21 to 30	1,285	1,330	1,158	1,051	1,172	1,248	1,308	1,259
31 to 40	3,215	3,100	3,456	2,602	3,048	3,143	3,132	3,186

INCREMENT IN CUBIC FEET

4 to 11	11.7	11.8	8.2	10.6	9.5	14.5	6.6	8.7
12 to 20	42.6	39.3	41.8	45.7	42.7	63.5	36.4	40.0
21 to 30	92.3	80.3	107.2	132.0	83.7	121.1	81.0	90.3
31 to 40	104.7	94.9	159.5	262.5	90.5	134.5	94.4	105.3

INCREMENT PER CENT

4 to 11	36.56	36.88	19.07	30.29	25.68	39.19	16.50	22.89
12 to 20	14.54	12.93	14.22	16.04	15.25	20.42	12.17	13.61
21 to 30	7.18	6.04	9.26	12.56	7.14	9.70	6.19	7.17
31 to 40	3.26	3.06	4.62	10.09	2.97	4.28	3.01	3.31

[a] Volume and increment of each group are sums of curved values for average trees. Increment for S 1, S 2, S 3, and S 4 is for period 1914–1919; for S 5, 1913–1918.

[b] Volume and increment for all divisions are based on new curves constructed from combined arithmetical averages, not averages of curved values shown in table.

RELATION BETWEEN VOLUME AND INCREMENT OF BLACKJACK AND YELLOW PINE

Since blackjack is younger than yellow pine, the volume and rate of growth are different. These differences are shown in Table VI, which is based on data from two groups of plots; namely, S 1, S 2, and S 3 and all silvicultural divisions of S 5. This grouping was necessary in order to give sufficient data for drawing curves. In Figure 9 the relationship between increment of blackjack and of yellow pine is shown on a volume basis.

Table VI shows that the average volume of yellow pine is much greater than the average volume of blackjack. Thus on plots S 1, S 2, and S 3 there is a difference of 34 cubic feet in the 12 to 20 inch diameter group and a difference of 236 cubic feet in the 21 to 30 inch

group. This amounts to differences of 11.6 and 21.9 per cent, respectively, in favor of yellow pine. On the three divisions of plot 5 there is a difference of 55 cubic feet in the 12 to 20 inch diameter group and a difference of 267 cubic feet in the 21 to 30 inch group. On a percentage basis the differences are 19.4 and 25.0, respectively,

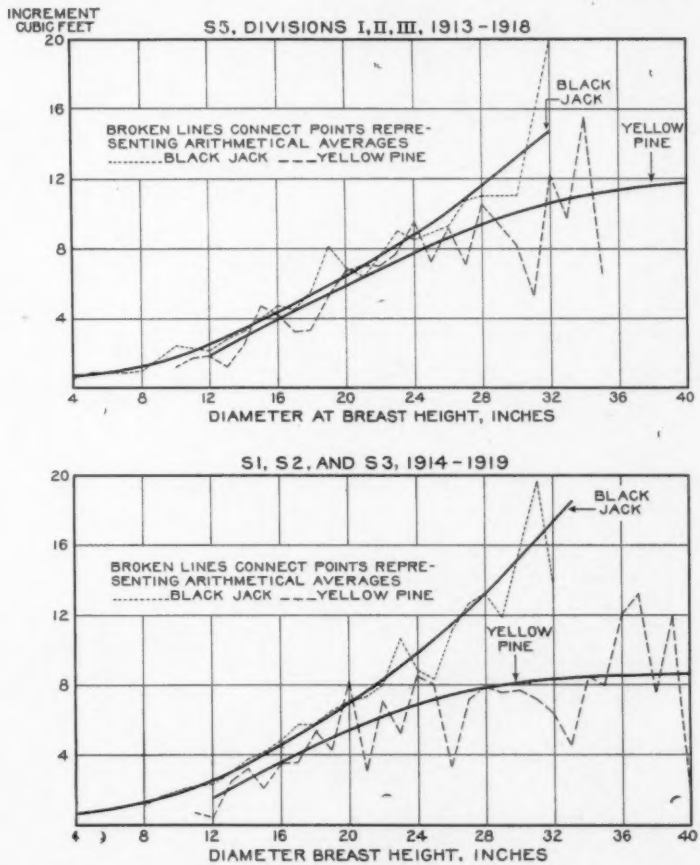

INCREMENT CUBIC FEET
S5, DIVISIONS I, II, III, 1913-1918
BLACK JACK
YELLOW PINE
BROKEN LINES CONNECT POINTS REPRESENTING ARITHMETICAL AVERAGES
.....BLACK JACK ---YELLOW PINE
DIAMETER AT BREAST HEIGHT, INCHES
S1, S2, AND S3, 1914-1919
BLACK JACK
YELLOW PINE
BROKEN LINES CONNECT POINTS REPRESENTING ARITHMETICAL AVERAGES
.....BLACK JACK ---YELLOW PINE
DIAMETER BREAST HEIGHT, INCHES

FIG. 9.—Increment of blackjack and yellow pine; based on data from the intensive plots

in favor of yellow pine. The greater difference in percentage of volume for the 21 to 30 inch diameter groups is due to the fact that blackjacks of this size are generally trees which have grown in an isolated position. Such trees are much shorter than yellow pines of the same diameter; they also have long and wide crowns and consequently their stems taper rapidly.

TABLE VI.—*Volume and increment of blackjack and yellow pine by diameter groups*[a]

[Based on data from intensive plots]

PLOTS S 1, S 2, AND S 3, COMBINED

Diameter class	Blackjack			Yellow pine		
	Volume, 1914	Increment, 1914–1919		Volume, 1914	Increment, 1914–1919	
	Cu. ft.	*Cu. ft.*	*Per cent*	*Cu. ft.*	*Cu. ft.*	*Per cent*
4 to 11	37	9.7	26.22			
12 to 20	292	42.1	14.42	326	31.4	9.63
21 to 30	1,077	112.2	10.42	1,313	71.8	5.47
31 to 40				3,094	84.8	2.74

PLOT S 5, DIVISIONS I, II, AND III, COMBINED

4 to 11	39	9.9	25.38			
12 to 20	284	40.0	14.08	339	35.1	10.35
21 to 30	1,067	99.0	9.28	1,334	83.7	6.27
31 to 40				3,157	112.2	3.55

[a] Volume and increment of each group are sums of curved values for average trees.

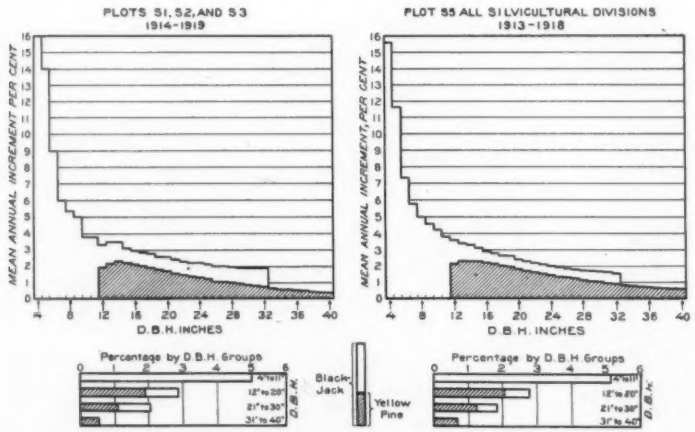


FIG. 10.—Relation between increment of blackjack and yellow pine compared on the basis of mean annual increment per cent. Based on data from intensive plots for 5-year period

Since the volume of yellow pine is greater than that of blackjack the difference in increment should be compared on a percentage basis. This comparison is graphically shown in Figure 10. It will be seen that the growth of blackjack is faster. The results show the necessity of selecting blackjack and yellow pine in the right proportions among those trees taken as a basis for determining the volumes and increments of average trees.

RELATION BETWEEN INCREMENT OF THRIFTY AND UNTHRIFTY TREES

Among other factors which must be considered in analyzing the growth of trees is their degree of vigor. Trees in the yellow pine stands of the Southwest become unthrifty as the result of one or more or all of the following causes: Mistletoe infection, insect and fungus attack, fire damage, lack of moisture, and suppression. Among these agencies mistletoe infection and crown suppression are the most prevalent as well as the most efficacious in retarding growth. Since western yellow pine is an extremely intolerant species the effects of crown suppression are very marked and may easily be detected. In cut-over stands suppression and mistletoe infection are chiefly operative in the unthinned and dense groups of blackjacks. In the

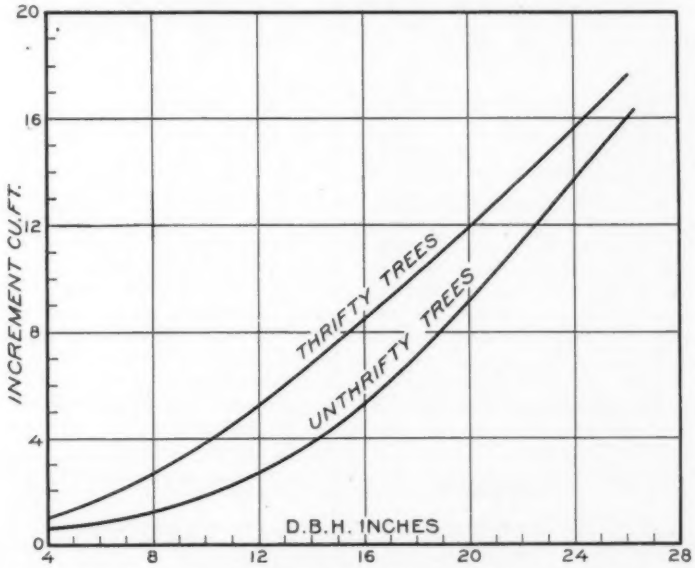


FIG. 11.—Periodic increment of mistletoe-infected blackjack based on data from intensive plot S 3

yellow pine groups as many as possible of the infected and suppressed individuals are removed at the time the stands are cut over.

Table VII shows the increment of thrifty and unthrifty blackjacks and thrifty and unthrifty yellow pines. Figure 11 shows the difference in these increments for blackjacks on the basis of curved values. The differences in increment per cent for both blackjack and yellow pine are shown in Figure 12. In general, the greatest difference occurs in the lower diameter classes, especially in the case of blackjacks.

The silvicultural significance of the foregoing is that unthrifty trees should, whenever possible, be removed at the time of cutting. If young stands of blackjacks, especially, were so thinned as to remove suppressed individuals, a decided increase in net increment would be obtained.

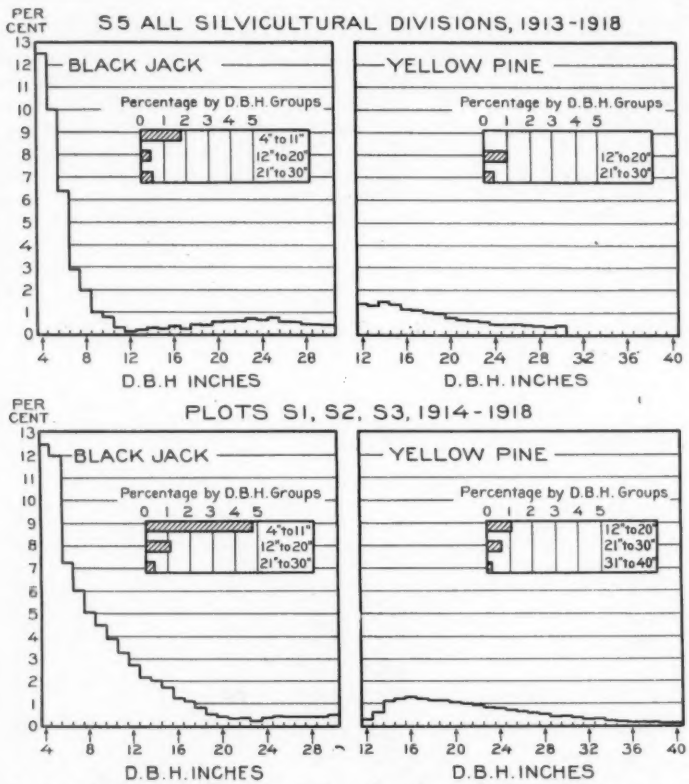


FIG. 12.—Relation between increment of thrifty and unthrifty trees in terms of excess growth of thrifty trees. Based on intensive plots for 5-year period

TABLE VII.—*Increment of thrifty and unthrifty trees by diameter groups* [a]

[Based on data from intensive plots]

PLOTS S 1, S 2, AND S 3

Diameter class	Thrifty trees			Unthrifty trees			Difference in increment, per cent [b]
Inches							
Blackjack:	*Cu. ft.*	*Cu. ft.*	*Per cent*	*Cu. ft.*	*Cu. ft.*	*Per cent*	
4 to 11	36	13.2	36.67	40	5.1	12.75	23.92
12 to 20	291	49.0	16.84	288	32.5	11.28	5.56
21 to 30	1,055	110.4	10.46	1,035	86.8	8.39	2.07
31 to 40							
Yellow pine:							
4 to 11							
12 to 20	326	40.5	12.42	337	23.7	7.03	5.39
21 to 30	1,380	105.0	7.61	1,308	57.6	4.40	3.21
31 to 40	3,193	142.3	4.46	2,912	100.9	3.46	1.00

[a] Volume and increment of each group are sums of curved values for average trees.

[b] Increment of unthrifty trees subtracted from increment of thrifty trees. Data for plots S 1, S 2, and S 3 are for period 1914-1919; plot S 5, 1913-1918.

TABLE VII.—*Increment of thrifty and unthrifty trees by diameter groups*—Con.

PLOT S 5, ALL SILVICULTURAL DIVISIONS

Diameter class	Thrifty trees			Unthrifty trees			Difference in increment, per cent
Inches							
Blackjack:	*Cu. ft.*	*Cu. ft.*	*Per cent*	*Cu. ft.*	*Cu. ft.*	*Per cent*	
4 to 11	40	10.3	25.75	34	5.7	16.76	8.99
12 to 20	286	40.1	14.02	283	33.7	11.91	2.11
21 to 30	1,093	107.6	9.84	1,271	91.7	7.21	2.63
31 to 40							
Yellow pine:							
4 to 11							
12 to 20	346	42.0	12.14	282	19.9	7.06	5.08
21 to 30	1,334	89.3	6.69	1,340	61.8	4.61	2.08
31 to 40	(a)			(a)			

a Insufficient data.

RELATIVE INCREMENT OF TREES IN DIFFERENT CROWN CLASSES

Table VIII shows the rate of growth of trees on the basis of crown form, only trees free from disease or insect attacks being included. The crown classifications are more or less arbitrary, and so far as effective crown area is concerned some trees probably belong in other classes. In the crown classification, for example, X trees include those left after the stand was cut, as well as those which always grew in the open. The crown areas of X trees are therefore extremely variable. Again as applied to western yellow pine stands, C trees are generally those which stand on the outer edges of a group. Their crowns are generally one sided, but the crown area of such trees may not be materially less than that of X or D trees. A group may consist of several codominant, intermediate, and suppressed individuals, but generally one or more dominant trees stand in the center of such a group. By virtue of their position in relation to light, dominant trees usually grow at a decidedly faster rate than the rest of the trees in the group.

TABLE VIII.—*Increment per cent of trees, by crown classes, on the basis of cubic foot volume*

[Based on data from intensive plots]

Diameter class	Plots S 1, S 2, and S 3, 1914 to 1919; crown classes a					Plots S 5, I, II, and III, 1913 to 1918; crown classes a				
	X	D	C	I	S	X	D	C	I	S
Blackjack:										
4	118.0	109.4	79.0	55.3	4.0	82.0	126.0	43.5	40.0	14.1
5	118.0	100.0	81.0	26.5	23.8	97.4	76.3	72.3	36.5	12.8
6	46.4	67.2	54.2	20.9	24.3	58.3	51.4	44.4	25.6	12.1
7	50.9	61.0	45.5	25.3	12.2	56.4	52.2	22.5	15.1	6.3
8	69.2	50.0	26.9	20.6	21.4	38.0	71.2	20.6	22.1	6.0
9	57.4	43.2	30.2	16.8	11.9	41.8	42.2	24.0	18.1	
10	40.2	47.3	27.7	19.5	3.4	30.2	33.5	18.2	5.2	
11	35.9	21.9	21.3	24.2		30.0	25.8	18.9	18.1	
12	37.5	18.7	18.4	10.2		14.0	22.3	14.6	8.2	

a X=trees in open; D=dominant trees; C=codominant trees; I=intermediate trees; S=suppressed trees. The crown classes are designated according to the standard classification used by the Forest Service Under suppressed trees only those free from disease or insects are included.

TABLE VIII.—*Increment per cent of trees, by crown classes, on the basis of cubic foot volume*—Continued

Diameter class	Plots S 1, S 2, and S 3, 1914 to 1919; crown classes					Plots S 5, I, II, and III, 1913 to 1918; crown classes				
	X	D	C	I	S	X	D	C	I	S
Blackjack—Con.										
13	25.5	19.5	16.1	17.5		23.5	11.1	13.0	5.5	
14	24.3	19.7	13.6	3.3	9.4	22.3	13.8	18.1	25.5	
15	27.7	19.4	15.3	12.1	13.1	19.0	15.7	19.2	11.0	
16	27.0	16.7	22.2			19.4	18.2	12.3	6.8	
17	18.5	21.0	16.5			13.4	13.2	11.7	5.2	
18	16.4	16.3	16.2	14.3		15.1	14.3	10.8		
19	14.1	17.5	12.4			32.1	11.8	14.5	7.5	
20	14.2	22.5	10.0			11.1	11.0	14.5		
21	15.1	11.0	11.0			9.8	11.2	14.0		
22	17.0	13.2	10.5			14.1	10.0	8.8		
23	11.0	11.9	20.8	3.5		13.0	8.3	6.5		
24	11.9	10.2	73.1			12.4	4.1	6.4		
25	11.1	5.4	6.4			14.5		8.8		
26	11.7	8.5				9.5	7.4	8.1		
27	7.8	9.8				11.6		4.4		
28	5.0	11.0				9.6				
Yellow pine:										
12			4.2			15.4	15.5		26.6	6.0
13			11.7	14.0				3.3		
14			14.6				10.6	3.1		
15	14.3	8.6	2.3			22.2			17.0	
16	17.1		13.6	23.7		17.0	5.3	21.6		
17		15.5	8.1			7.3	14.6	13.7	6.7	
18	14.8		21.0			11.0	12.5	8.3		
19	19.0	6.2	9.7	6.5		10.4	4.8			
20	13.5	18.1	24.4			4.0	2.7	1.4		
21	6.9	4.9	7.0			14.4	8.0	7.9		
22	8.6	8.8	9.8			8.2	6.6	6.4		
23		7.8	6.8			10.2	9.7	4.4		
24	15.5		6.9			7.9	8.4	6.2		
25	4.8	11.9	12.4			6.1	5.3	4.4		
26	3.5					8.4	8.3	3.7		
27	5.3					8.0	1.6	1.1		
28		12.5	6.1			9.3	4.6	6.6		
29	4.6	3.1				5.2	3.1			
30	5.4	5.0		10.3		5.3	2.6	2.5		
31	6.7	4.7				2.4	3.4	0.9		
32	6.8					4.2	1.7			
33	2.0					3.3				
34	5.0					7.0				
35						2.3				
36	3.2					5.5				

Because of the few trees on which the growth measurements in some diameter classes are based, no consistent curves could be constructed. For the same reason the percentage values shown in Table 8 are somewhat irregular and in some diameter classes the reverse of what would be expected. This applies principally to yellow pines of which there are only one or two trees in each crown class of any one diameter class. In such instances other factors than crown area may have a preponderating influence in determining the degree of growth.[10] In general, however, the open-growing and dominant trees lead in growth percentage with codominant trees closely following. Limited as the data are, they nevertheless indicate the importance of taking the crown development of trees into con-

[10] It has been found, for instance, that trees isolated as a result of cutting other members of the group, or open-grown trees near which other individuals or groups of trees are felled, show a great response in growth. The acceleration occurs not only on young trees but on mature trees as well. Some results of such a study are cited a little later in this report. A more detailed report is given by the author in the Journal of Forestry. KRAUCH, H. ACCELERATION OF GROWTH IN WESTERN YELLOW PINE STANDS AFTER CUTTING. Jour. Forestry 22 (6): 39–42. 1924.

sideration when comparing the growth of trees on different areas. They also show the advisability of reserving trees with well-developed crowns.

Periodic Increment of Average Trees

As S 1, S 2, S 3, and S 4 have been twice remeasured since they were established, the periodic increment of the trees on these plots is determinable. The compilation was made on the basis of diameter increase. Corresponding volume increase was obtained by projecting diameter values on a volume curve, according to the method illustrated in Figure 4. The results are given in Table IX, which shows the relationship between increment during the two consecutive periods.

Table IX.—*Periodic increment of thrifty blackjacks and of all trees on plots*

[Based on data from intensive plots]

THRIFTY BLACKJACK

Plot and diameter class	Volume 1909 *	Increment by periods *				Percentage of increase of second period over first
		1909 to 1914	1914 to 1919	Total 10 years		
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Per cent*	*Per cent*
Plot S 1:						
4 to 11	37	12.8	14.6	27.4	74.1	14.1
12 to 20	292	39.4	50.1	89.5	30.7	27.2
21 to 25	406	39.1	51.2	90.3	22.2	30.9
Plot S 2:						
4 to 11	37	14.6	18.2	32.8	88.6	24.7
12 to 20	292	45.9	55.0	100.9	34.6	19.8
21 to 25	406	48.0	52.2	100.2	24.7	8.8
Plot S 3:						
4 to 11	37	7.3	12.7	20.0	54.1	74.0
12 to 20	292	30.5	46.1	76.6	26.2	51.1
21 to 25	406	28.4	44.7	73.1	18.0	57.4
26 to 30	671	34.6	61.7	96.3	14.4	78.3
Plot S 4:						
4 to 11	35	6.8	14.6	21.4	61.1	114.7
12 to 20	285	20.7	46.8	67.5	23.7	126.1
21 to 25	395	18.7	43.7	62.4	15.8	133.7
26 to 30	656	24.4	57.4	81.8	12.5	135.2

ALL TREES

Plot S 1:						
4 to 11	32	11.8	13.7	25.5	79.7	16.1
12 to 20	293	39.5	48.8	88.3	30.1	23.5
21 to 30	1,285	89.2	105.2	194.4	15.1	17.9
Plot S 2:						
4 to 11	32	13.0	15.5	28.5	89.1	19.2
12 to 20	304	41.0	51.4	92.4	30.4	25.4
21 to 30	1,330	78.6	86.1	164.7	12.4	9.5
Plot S 3:						
4 to 11	43	6.8	10.0	16.8	39.1	47.1
12 to 20	294	30.7	41.6	72.3	24.6	35.5
21 to 30	1,158	77.3	115.5	192.8	16.6	49.4
Plot S 4:						
4 to 11	35	6.2	13.9	20.1	57.4	124.2
12 to 20	285	21.5	48.9	70.4	24.7	127.4
21 to 30	1,207	53.1	122.0	175.1	14.5	129.8

* Volume and increment of each group are sums of curved values for average trees.

On all plots increment of thrifty blackjacks is greater for the second period than it is for the first. The difference in increment is also generally greatest in the higher diameter classes. The same relationship applies where all trees on the plots are involved.

Although the foregoing results show that the trees grew more during the second 5-year period than during the first 5-year period following the establishment of the plots, these differences can not be entirely ascribed to the accelerative effects of cutting part of the stand. They are probably largely due to differences in total precipitation occurring during the respective periods involved. Records kept at the Southwestern Experiment Station show that a total of 95 inches of precipitation fell during the first period and 125 inches during the second period, an excess of 30 inches, or 31.6 per cent during the latter period.

Differences in periodic increments, therefore, do not in themselves reveal the effects of cutting. Increment after cutting should really be compared with the growth in corresponding periods before cutting. Such determinations have been made in this study but the data have not as yet been compiled for all of the plots. Increment borings taken from trees on an old cutting near the Southwestern Experiment Station showed that response of released trees was very great. The average growth of 45 trees between 15 and 20 inches in diameter was 4.43 inches in 25 years after the stand was cut, as compared with a growth of 0.97 inches before cutting. Likewise, the average growth of 61 trees between 21 and 26 inches in diameter was 5.75 inches in 25 years after cutting as compared with 1.37 inches before cutting. These results show conclusively that acceleration of growth is maintained for many years following the cutting of part of the stand.

ANALYSIS OF VOLUME AND INCREMENT OF STANDS

The foregoing discussions deal with the volume and increment of average trees, rather than with the stand as a whole. In a previous section it was shown how the volume and increment of the stand are computed. The results of these computations reveal a number of facts which it is well to point out. They refer to the extensive plots.

Distribution of Volume

Figures 13 and 14 show the distribution of volume by diameter classes. It will be noted that this distribution is similar for all plots—that is, a fairly gradual increase in volume from the 4-inch class up to a diameter of about 22 inches; then a more or less gradual reduction in volume in the higher diameter classes. The distribution for a very large area would probably be represented by a smooth curve, as indicated by Figure 15, which shows the differences in distribution on extensive and intensive plots, in percentages of board-foot volumes. In almost every case the distribution is much more regular on the extensive than on the intensive plots. The nearest approach to normal distribution occurs on the largest plots—namely, extensive plots S 3 and S 4. That the irregularity of distribution on small areas can not be obviated by a more careful selection of plots, is shown in Figure 16, where the many small intensive plots of S 5 reveal in the aggregate the same irregularity as do those of S 1, S 2, S 3, and S 4.

Distribution of Increment

The black bars in Figures 13 and 14 show the distribution of net increment. The same values are later represented in Figures 17 and 18, where, in addition, the mortality occurring in each diameter class

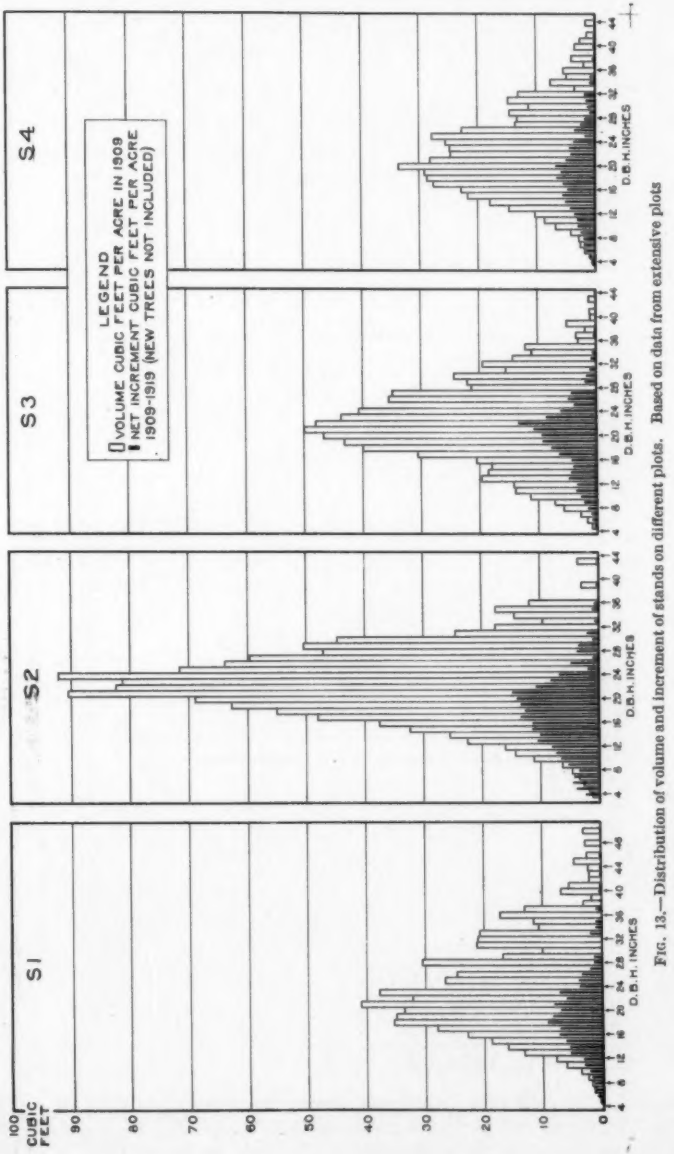


FIG. 13.—Distribution of volume and increment of stands on different plots. Based on data from extensive plots

is shown. The volume of new trees which usually figures as part of the periodic increment is not included in these compilations.

A comparison of the increment graphs with the volume graphs shows that they are similar in form. In the higher diameter classes

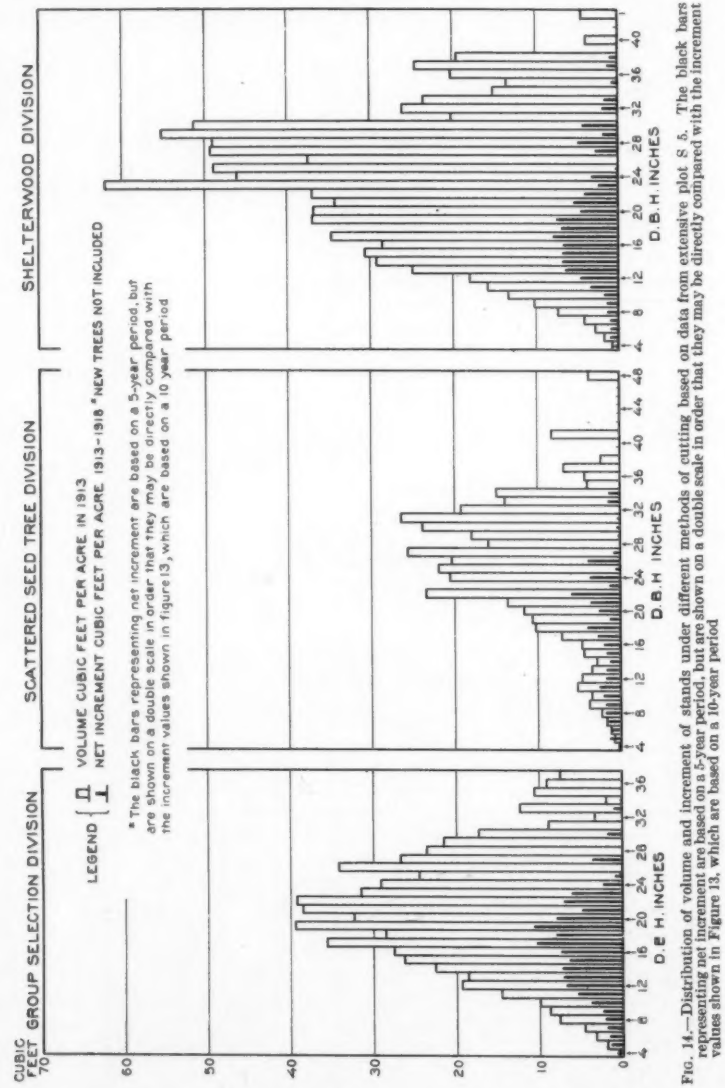

CUBIC FEET
GROUP SELECTION DIVISION
SCATTERED SEED TREE DIVISION
SHELTERWOOD DIVISION
LEGEND
VOLUME CUBIC FEET PER ACRE IN 1913
NET INCREMENT CUBIC FEET PER ACRE 1913-1918 *NEW TREES NOT INCLUDED
* The black bars representing net increment are based on a 5-year period, but are shown on a double scale in order that they may be directly compared with the increment values shown in figure 13, which are based on a 10 year period
D.B.H. INCHES

FIG. 14.—Distribution of volume and increment of stands under different methods of cutting based on data from extensive plot S 5. The black bars representing net increment are based on a 5-year period, but are shown on a double scale in order that they may be directly compared with the increment values shown in Figure 13, which are based on a 10-year period

increment falls off more abruptly, however, than does volume. This is due chiefly to the proportionally greater mortality among the older and larger trees; in fact, mortality becomes so great that it almost

offsets or even surpasses the net increment. This relationship between net increment and mortality is revealed by a study of Figures

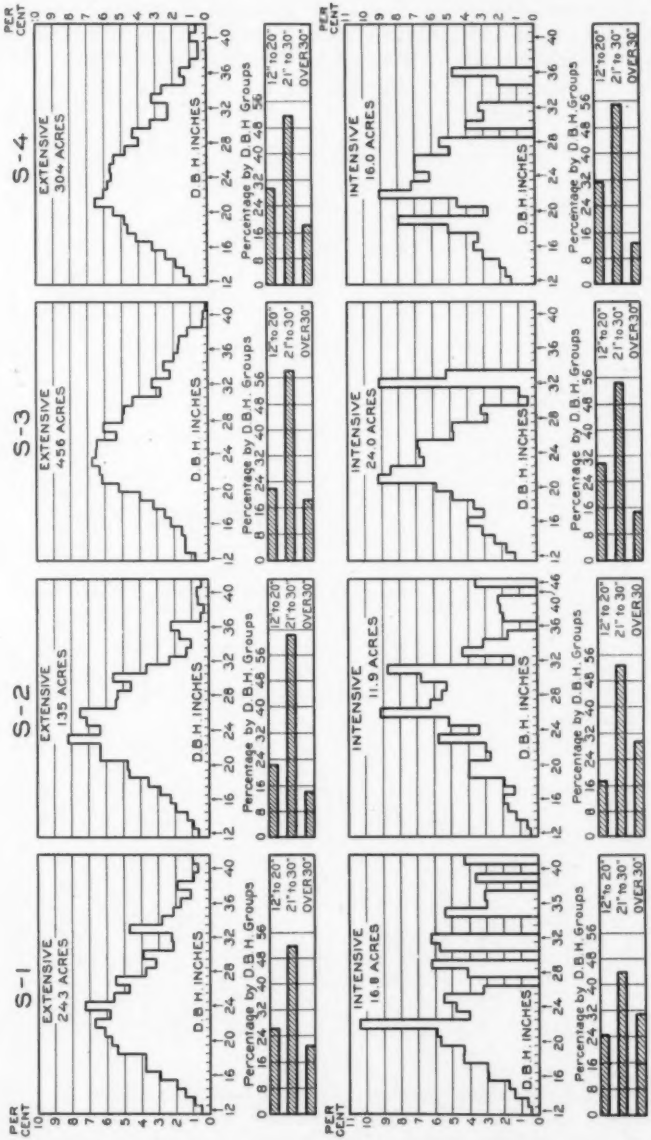


FIG. 15.—Distribution of volume on extensive and intensive sample plots compared on the basis of percentages of total merchantable board-foot volumes

17 and 18. The matter is further discussed in connection with mortality in stands.

Comparison of Increment on Different Plots

Table X shows the volume, gross and net annual increment, and the increment percentage for each plot by diameter groups. A comparison of the percentage values shows that the greatest increment percentage occurs in the 4 to 11 inch group. The other groups

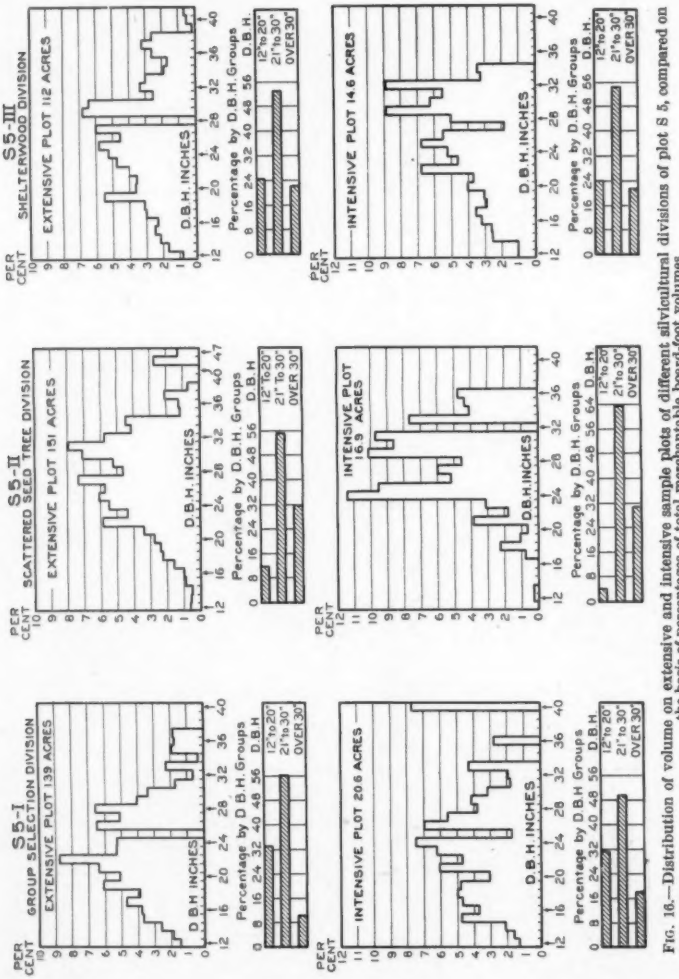


Fig. 16.—Distribution of volume on extensive and intensive sample plots of different silvicultural divisions of plot S 5, compared on the basis of percentages of total merchantable board-foot volumes

follow with diminishing percentages, and for trees above 30 inches in diameter there is, in several cases, a net decrease. The economic value of short cutting cycles is thus indicated. But considering the distribution of diameter classes as they exist on the various plots, it will be seen that the highest net volume increment occurs in the

12 to 20 inch group, although the basic volume of this group is in all cases lower than that for the 21 to 30 inch group. In other words, the wood capital represented by the 21 to 30 inch group, although considerably greater than that represented by the 12 to 20 inch group has, in 10 years, given a lower return of interest. The value of determining the increment of stands by diameter classes is thus evident; it shows where the greatest increment is occurring and whether or not the retention of large trees is justified.

TABLE X.—*Volume, mean annual increment, and mortality in stands*[a]

ORIGINAL VOLUME IN CUBIC FEET

Diameter class	S 1	S 2	S 3	S 4	S 5		
					I	II	III
4 to 11	16.1	44.2	43.2	27.3	51.5	18.9	56.7
12 to 20	210.1	368.5	250.7	205.5	250.3	60.0	272.8
21 to 30	263.7	683.2	348.5	206.2	285.8	200.4	470.4
31 to 40	127.4	98.0	87.0	58.5	53.2	92.2	166.2
Over 40	23.8	3.5	2.4	5.2	----	12.2	4.3
Total	641.1	1,197.4	731.8	502.7	640.8	383.7	970.4
12 inches up	625.0	1,153.2	688.6	475.4	589.3	364.8	913.7

GROSS INCREMENT[b]

Diameter class	S 1		S 2		S 3		S 4		S 5					
									I		II		III	
	Cubic feet	Per cent	Cubic feet	Per cent	Cubic feet	Per cent	Cubic feet	Per cent	Cubic feet	Per cent	Cubic feet	Per cent	Cubic feet	Per cent
4 to 11	1.13	7.02	3.97	8.98	1.48	3.43	1.51	5.53	2.55	4.95	1.57	8.31	1.80	3.17
12 to 20	6.34	3.02	11.25	3.05	6.07	2.42	5.08	2.47	7.96	3.18	2.52	4.20	6.79	2.49
21 to 30	4.52	1.71	9.32	1.36	6.68	1.92	3.54	1.72	4.65	1.63	4.25	2.12	6.27	1.33
31 to 40	1.05	.82	.64	.65	.86	.99	.75	1.28	.37	.69	.96	1.04	1.09	.66
Over 40	.09	.38	.01	.29	.01	.42	.05	.96	----	----	.07	.57	.02	.47
Total and av.	13.13	2.05	25.19	2.10	15.10	2.06	10.93	2.17	15.53	2.42	9.37	2.44	15.97	1.65
12 inches up	12.00	1.92	21.22	1.84	13.62	1.98	9.42	1.98	12.98	2.20	7.80	2.14	14.17	1.55

MORTALITY

4 to 11	0.01	0.06	0.13	0.29	0.30	0.69	0.07	0.26	0.61	1.18	0.27	1.43	0.62	1.09
12 to 20	.41	.20	.91	.25	.77	.31	.48	.23	.60	.24	.63	1.05	.87	.32
21 to 30	.94	.36	3.84	.56	1.28	.37	.78	.38	2.57	.90	2.39	1.19	3.29	.70
31 to 40	1.00	.78	.59	.60	.90	1.03	.21	.36	1.98	3.72	1.88	2.04	1.48	.89
Over 40	.77	3.24	----	----	----	----	----	----	----	----	1.13	9.26	----	----
Total and av.	3.13	.49	5.47	.46	3.25	.44	1.54	.31	5.76	.90	6.30	1.64	6.26	.65
12 inches up	3.12	.50	5.34	.46	2.95	.43	1.47	.31	5.15	.87	6.03	1.65	5.64	.62

NET INCREMENT

4 to 11	1.12	6.96	3.84	8.69	1.18	2.74	1.44	5.27	1.94	3.77	1.30	6.88	1.18	2.08
12 to 20	5.93	2.82	10.34	2.80	5.30	2.11	4.60	2.24	7.36	2.94	1.89	3.15	5.92	2.17
21 to 30	3.58	1.35	5.48	.80	5.40	1.55	2.76	1.34	2.08	.73	1.86	.93	2.98	.63
31 to 40	.05	.04	.05	.05	−.04	−.04	.54	.92	−1.61	−3.03	−.92	−1.00	−.39	−.23
Over 40	−.68	−2.86	.01	.29	.01	.42	.05	.96	----	----	−1.06	−8.69	.02	.47
Total and av.	10.00	1.56	19.72	1.64	11.85	1.62	9.39	1.86	9.77	1.52	3.07	.80	9.71	1.00
12 inches up	8.88	1.42	15.88	1.38	10.67	1.55	7.95	1.67	7.83	1.33	1.77	.49	8.53	.93

[a] Increment and mortality for S 1, S 2, S 3, and S 4 based on 10-year period; increment and mortality for S 5 I, II, and III based on 5-year period.
[b] Gross increment is total increment before mortality is deducted.

A fact revealed in comparing percentage increments and volume increments for the various plots is that one figure does not serve as an index of the other. For instance, although plot S 3 shows a net periodic volume increment of 11.85 cubic feet per acre as against 19.72 cubic feet per acre on plot S 2, the respective percentages of increment are 1.62 and 1.64. The difference in volume increment is 7.87 cubic feet or 66.4 per cent, whereas the difference between percentages of increment is 0.02, or only slightly more than 1.2 per cent. Again, on the group selection division of plot S 5, the net mean annual volume increment is 9.77 cubic feet and the increment percentage, 1.52. On the shelterwood division the volume increment is 9.71 cubic feet and the increment percentage, 1.0. The difference in volume amounts to only 0.06 cubic foot, or a little over 0.6 per cent. The difference between percentages of increment is 0.52, or 52 per cent. These relationships are still more strikingly revealed by comparing the values on the basis of gross increment. It is therefore obvious that the average increment percentage as determined from a sample area can not be safely applied in determining the increment of any other area even though the total volume of that area has been previously obtained. What must be done is to determine the increment of each diameter class separately, in the manner previously described.

That the rate of growth of average trees gives no clue to the increment of the stand as a whole will be perceived from the following comparison. Figure 8 shows that the increment of average trees on plot S 5 is much greater on the scattered seed tree division (II) than on the group-selection division (I). The total gross volume increments for these divisions are, however, 9.37 and 15.53 cubic feet, respectively. The corresponding percentage increments are practically the same—namely, 2.44 and 2.42.

MORTALITY IN STANDS

Under present economic conditions the trees which die in cut-over stands can not be profitably salvaged; their volume must, therefore, be deducted from the increment put on by the surviving trees. The difference represents the net increment. Since mortality greatly reduces the normal increment of stands it is well to show where and how mortality has affected the stands included in the present study.

RELATION OF MORTALITY TO INCREMENT

Figures 17 and 18 show the ratio of mortality to total increment for each diameter class. The entire bar represents total increment. The portion above the initial line represents the excess of increment over mortality, or in other words the net increment. Where mortality exceeds increment the net loss is indicated by a shaded bar. By plotting values in this manner it can be seen at a glance whether or not the net increment for a given diameter class, or group of diameter classes, is abnormal in relation to total increment. An abnormal relationship is, of course, due to excessive mortality, and is generally indicated by a very low net increment or an actual net loss. The fact that some of the higher diameter classes show a net increment is therefore no indication that the retention of trees in these classes is economically justified. But some mortality is to be expected and a reasonable allowance must be made for this factor.

Comparing values now on the different plots it will be seen that mortality increases as we pass from the lower to the higher diameter classes. The decided increase in mortality in the higher classes

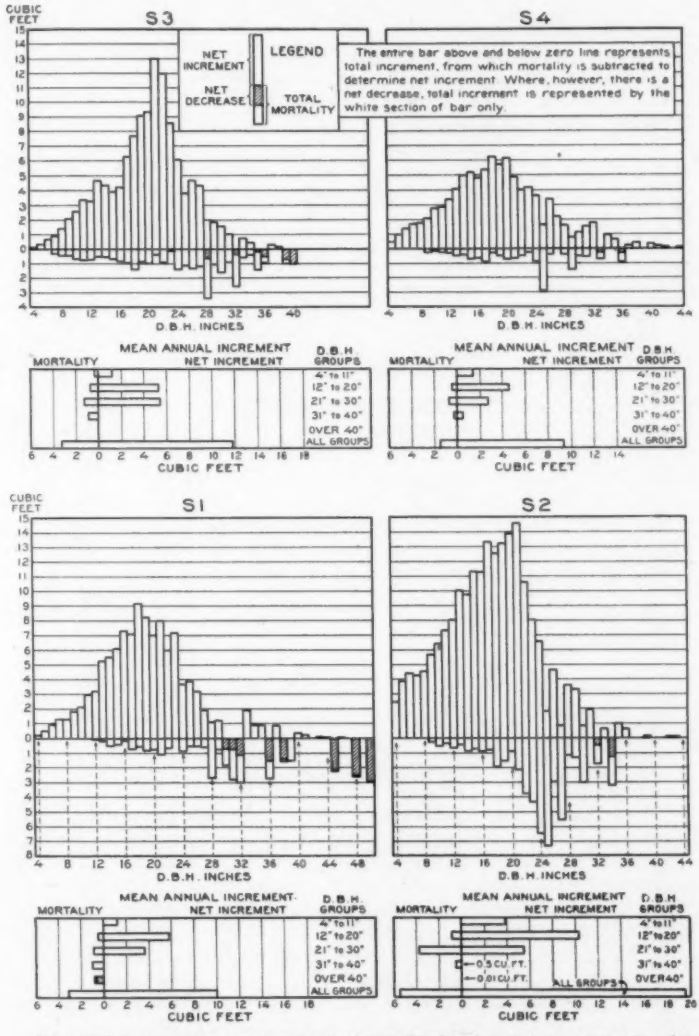


FIG. 17.—Relation between net increment and mortality based on data from extensive plots. Vertical bars represent increment and mortality per acre, exclusive of new trees, for 10-year period. Horizontal bars represent mean of 10-year period

accounts for the low net increment obtained in these classes. In some diameter classes mortality has even been so great as to effect a net decrease. By comparing mortality with total increment by

diameter groups (horizontal bars in Figures 17 and 18) it will be noted that in the groups above 30 inches in diameter, mortality is more than 50 per cent of the total increment, indicating an abnormal

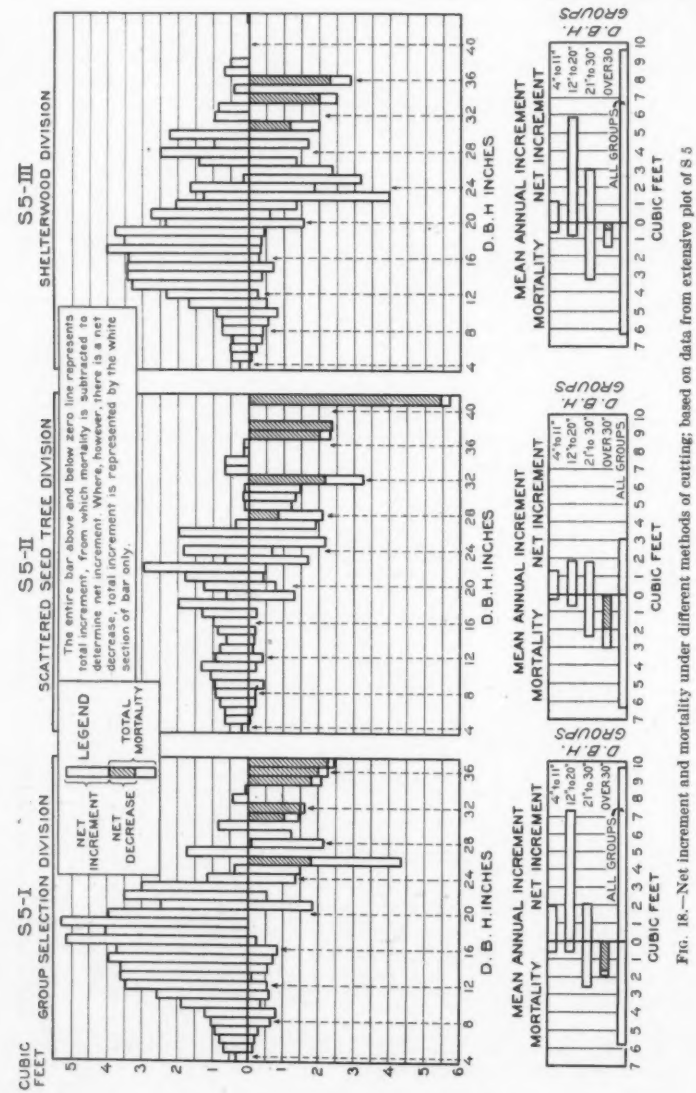


FIG. 18.—Net increment and mortality under different methods of cutting; based on data from extensive plot of S 5

relationship. In the groups below 30 inches in diameter of plots S 1, S 2, S 3, and S 4, mortality is decidedly less than half the total increment. On every silvicultural division of plot S 5, mortality is

relatively high even in the 21 to 30 inch group, amounting to more than 50 per cent of the total increment. The excessive mortality is due to the relatively large amount of windfall occurring in this group. But it should be borne in mind that the data for S 5 are based on a 5-year period only whereas the data for the other plots cover 10 years. It is to be expected that the second measurements of plot S 5 will show considerably less loss in the 21 to 30 inch group than did the first period and that therefore the relation of mortality to increment will compare favorably with the 10 years average for the other plots.

The important fact brought out by the foregoing comparisons is that mortality greatly reduces the increment which would otherwise be obtained and that both proportionally and quantitatively the greatest mortality occurs in the higher diameter classes. If the trees in the higher diameter classes are omitted, the total volume of the stand is considerably reduced; but the net increment obtained from this reduced volume is almost the same as that obtained from the whole stand, and in some cases is even greater. The present data indicate how greatly the loss of a few large trees offsets the increment of the stand and why increment should be determined for each diameter class separately so that the essential facts may be revealed.

From an economic standpoint it might in the present instance have been better if all of the largest trees had been cut. The present data, at least, indicate that no trees above 30 inches in diameter ought to have been retained. It is believed, however, that the greatest mortality among the large trees has already occurred. If this is true, then it is possible that by the time the next cut is made—at present estimated to be about 75 years from the date of the first cut—the increment of the surviving trees will have offset or even surpassed the mortality. Regardless of growth, the retention of some large trees for seed is necessary.[11]

The results which would have been obtained on the various plots if the dead trees could have been salvaged are shown in Table X under gross increment.

RELATION BETWEEN MORTALITY AND METHODS OF CUTTING

The relation of mortality to methods of cutting is shown by the results obtained on plot S 5 where three different methods are represented. It will be observed from the results given in Table X that volume of mortality is very much the same for all three methods. But in relation to total increment, there are big differences. Thus, although mortality is more than two-thirds of the total increment on the scattered seed-tree division, the volume of mortality is just about the same as on the shelterwood division where it is less than two-fifths of total increment. The results indicate that the percentage of mortality increases in inverse ratio to the degree of cutting; and Figure 19 shows that the greatest percentage of mortality is in the higher diameter classes.

[11] Pearson figures four trees per acre above 20 inches in diameter is needed to insure restocking where reproduction is lacking at the time of cutting. PEARSON, G. A. NATURAL REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST. U. S. Dept. Agr. Bul. 1105, p. 141. 1923.

PERIODIC MORTALITY

Since plots S 1, S 2, S 3, and S 4 were twice remeasured it was possible to determine the rate of mortality during two consecutive five-year periods. The results are shown graphically on a percentage basis in connection with net increment in Figure 20. On every plot the total mortality was greatest during the second period. The same relationship applies in most instances to each diameter group as well. The greatest differences in mortality between the two periods are generally found in the higher diameter classes.

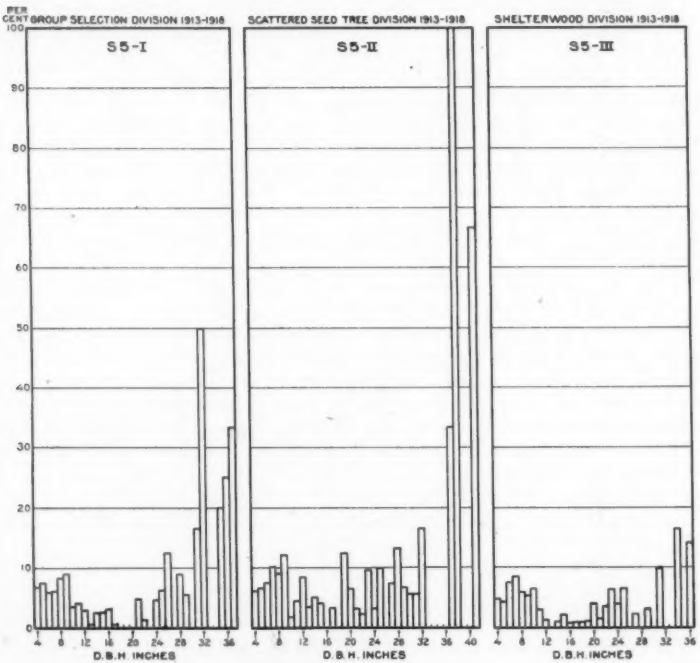
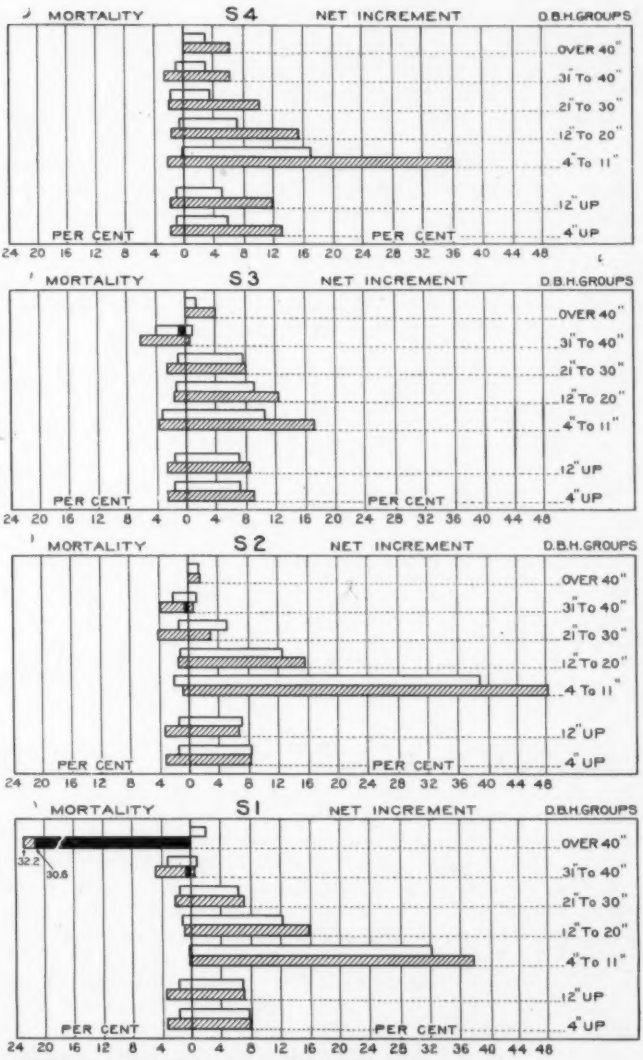


FIG. 19.—Percentage of mortality by volume under different methods of cutting. Based on data from extensive plot S 5, period of 1913–1918

Judging from the results obtained it appears as if mortality were increasing, but as individual records were not kept, it is somewhat doubtful whether all dead trees were correctly included in their respective periods. The total mortality for the two periods is, however, considered correct. Whether this increase in mortality will continue can not be predicted. But although mortality has increased there has also been, except in the case of plot S 2, a considerable increase in total increment. Therefore, in spite of the increase in mortality the net increment of the stands represented by these plots has also increased.



Total increment for first period, excluding new trees.

Total increment for second period, excluding new trees.

To the right of vertical line the length of bars represents net increment, or total increment minus mortality; to the left of line, mortality. A solid black section indicates a net loss, or the excess of mortality over total increment for the period

FIG. 20.—Periodic net increment and mortality on different plots, based on data from extensive plots for periods of 1909–1914 and 1914–1919

CAUSES OF MORTALITY

Table XI shows the percentage of mortality by causes on the basis of total volume. On plot S 1 lightning caused the greatest loss. Heavy mortality due to lightning is explained by the fact that although only a few trees may be struck they are usually large and therefore have a high volume content. Wind was also responsible for considerable loss on this plot during both periods. On plot S 2 the greatest percentage of mortality is ascribed to insects. Lightning and mistletoe infection follow in order, but during the second period wind was also responsible for considerable loss. On plot S 3 wind led all other causes, with mistletoe infection next in order. On plot S 4 during the first period lightning was responsible for the greatest mortality; during the second period insects caused the greatest loss. On plot S 5 wind greatly exceeded all other causes.

TABLE XI.—*Percentage of mortality by causes, based on volumes of dead trees*

Cause	Mortality for two consecutive periods								Mortality for one period, under different methods of cutting, 1913–1918		
	1909–1914				1914–1919						
	S 1	S 2	S 3	S 4	S 1	S 2	S 3	S 4	S 5–I	S 5–II	S 5–III
Wind	17.93	2.02	39.49	28.58	18.70	23.77	49.50	28.35	66.62	55.37	83.57
Lightning	42.80	37.70	20.79	45.08	37.20	16.40	19.50	11.55	------	9.28	------
Mistletoe	------	3.91	25.71	------	------	25.50	25.50	------	6.76	1.34	5.96
Insects	19.75	49.48	11.31	19.92	12.81	30.50	3.70	30.92	9.78	3.36	3.85
Porcupine	------	------	1.70	------	------	------	------	------	------	------	------
Supression	------	------	------	------	.09	.33	1.10	.23	------	------	------
Cut in trespass	11.10	6.75	------	------	------	------	------	.90	------	------	------
Other causes	8.42	.14	1.00	6.42	31.20	3.50	.70	28.05	16.84	30.65	6.62
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The causes given for mortality are based on the best evidence which could be found at the time that the plots were examined. Usually several agencies are involved, and the primary cause of mortality can not always be detected. For instance, wind may merely be a secondary cause; that is, trees may have been weakened or killed by other agencies, previous to being wind thrown or broken. Or, trees that appear to have been thrown by the wind may instead have been uprooted by the weight of heavy snow lodging in the crowns. Ordinarily trees struck by lightning are not killed outright but succumb to the western yellow pine beetle (*Dendroctonus brevicomis*), which usually attacks such trees. But, although the causes of mortality may not be correctly diagnosed for every tree, the averages are substantially correct.

A determination of the causes of mortality is important because it shows whether or not the agencies involved are controllable. If the causes of mortality are known it may be possible by modifying silvicultural methods to lessen future losses.

MORTALITY IN RELATION TO SIZE OF CUT-OVER AREAS

Table XII shows the relationship between live and dead trees on extensive and intensive plots. It will be noted that distribution and amount of mortality vary on plots of different sizes. Nor is there any consistent difference; in some cases mortality is greatest

on the extensive plots, in others it is greatest on the intensive plots. These inconsistencies are due to a number of factors which are extremely difficult to isolate. It is evident, however, that the lack of uniformity in the distribution of mortality necessitates obtaining mortality data from large areas.

TABLE XII.—*Mortality on extensive and intensive plots* [a]

Plot and diameter class	Number of trees per acre				Percentage of dead trees		Mortality, cubic feet per acre	
	Live		Dead					
	Extensive	Intensive	Extensive	Intensive	Extensive	Intensive	Extensive	Intensive
S 1:								
4 to 11	3.20	2.72	0.01	0.24	0.31	8.11	0.04	1.00
12 to 20	6.57	7.44	.12	.....	1.79	.....	4.11	.....
21 to 30	2.56	2.56	.08	.06	3.03	2.29	9.37	8.75
31 to 40	.45	.60	.04	.06	8.16	9.09	10.08	17.07
Over 40	.04	.....	.01	.....	20.00	.....	7.66	.....
Total	12.82	13.32	.26	.36	1.99	2.63	31.26	26.82
S 2:								
4 to 11	11.57	10.84	.17	.17	1.45	1.54	1.28	.50
12 to 20	11.25	10.08	.36	.08	3.10	.79	9.10	2.10
21 to 30	6.07	6.64	.33	.34	5.16	4.87	38.43	31.85
31 to 40	.38	1.00	.02	.08	5.00	7.41	5.85	32.43
Over 40	.01	.08	.....	.....	.....	.....	.....	.....
Total	29.28	28.64	.88	.67	2.92	2.29	54.66	66.88
S 3:								
4 to 11	6.38	10.66	.52	1.29	7.54	10.80	3.02	7.56
12 to 20	7.70	12.89	.25	.33	3.14	2.50	7.66	9.25
21 to 30	3.69	4.08	.11	.....	2.89	.....	12.79	.....
31 to 40	.32	.37	.03	.....	8.57	.....	9.00	.....
Over 40	.04	.....	.....	.....	.....	.....	.....	.....
Total	18.13	28.00	.91	1.62	4.78	5.47	32.47	16.81
S 4:								
4 to 11	5.93	7.88	.18	.18	2.95	2.23	.68	.56
12 to 20	6.82	10.00	.17	.....	2.43	.....	4.76	.....
21 to 30	2.30	3.56	.08	.19	3.36	5.07	7.77	18.50
31 to 40	.27	.37	.01	.06	3.57	13.95	2.14	19.40
Over 40	.01	.....	.....	.....	.....	.....	.....	.....
Total	15.33	21.81	.44	.43	2.79	1.93	15.35	38.46
S 5, I:								
4 to 11	10.51	11.40	.67	.53	5.99	4.44	3.04	2.96
12 to 20	9.00	9.38	.14	.14	1.53	1.47	3.03	3.74
21 to 30	2.93	3.10	.12	.10	3.93	3.12	12.85	10.29
31 to 40	.20	.34	.04	.05	16.67	12.82	9.90	10.92
Over 40	.....	.....	.....	.....	.....	.....	.....	.....
Total	22.64	24.22	.97	.82	4.11	3.27	28.82	27.91
S 5, II:								
4 to 11	4.66	4.91	.37	.65	7.36	11.69	1.34	2.24
12 to 20	1.80	.89	.09	.....	4.76	.....	3.16	.....
21 to 30	1.80	2.37	.10	.18	5.26	7.06	11.97	23.90
31 to 40	.35	.47	.03	.06	7.89	11.32	9.40	13.13
Over 40	.03	.....	.01	.....	25.00	.....	5.65	.....
Total	8.64	8.64	.60	.89	6.49	9.34	31.52	39.27
S 5, III:								
4 to 11	10.33	11.57	.61	.75	5.58	6.09	3.09	4.49
12 to 20	9.19	13.76	.12	.41	1.29	2.89	4.33	10.68
21 to 30	3.97	5.82	.15	.20	3.64	3.32	16.42	23.50
31 to 40	.58	.95	.03	.21	4.92	18.10	7.42	56.77
Over 40	.01	.....	.....	.....	.....	.....	.....	.....
Total	24.08	32.10	.91	1.57	3.64	4.66	31.26	95.44

[a] Mortality for plots S 1, S 2, S 3, and S 4 represents 10-year period; mortality for plot S 5 represents 5-year period.

SUMMARY

In compiling the growth data obtained from certain extensive and intensive plots established in cut-over stands of western yellow pine in Arizona it was found that these plots did not agree as to distribution of diameter classes or volume per acre. Further investigation also showed that even the larger plots were not representative of more extensive areas and that to obtain reliable increment data on an acre basis it would be necessary to lay out plots of such size that they could no longer be considered as sample plots. Some other method was, therefore, sought whereby the increment of western yellow pine stands could be economically yet accurately determined.

The chief characteristic of this method is that it employs the tree rather than area as the unit of measurement. Instead of periodically measuring all trees on a restricted area, a limited number of individual trees in each diameter class are selected, so distributed that they cover all conditions of site, age, vigor, and crown class, and these are carefully measured for both diameter and height growth. The data obtained on the basis of these trees are then applied to a stand table previously determined from a survey of extensive blocks or strips. Although the method was devised especially for western yellow pine, it can be applied as well to stands of other species. The main advantages of this method over the sample-plot method are these:

(1) The method is applicable to stands which are not uniformly stocked, whereas the acreage-basis method is not.

(2) The increment of stands can be more economically determined because only a small percentage of the trees are measured.

(3) Because the growth of the same trees is followed up through successive periods, it is possible to tell in which diameter classes the maximum increment is occurring. This information is important from a management standpoint.

(4) It permits a detailed analysis of growth on the basis of age, vigor, and crown development of trees, thereby yielding information of silvicultural value.

In addition to a discussion of method, the following facts regarding the increment of western yellow pine trees and stands have been brought out in this report.

(1) Increment of average trees varies directly with their age, vigor, and effective crown areas. Growth is well maintained in blackjacks, regardless of their size, whereas in yellow pines it falls off in the higher diameter classes. However, where the trees have thrifty and well-developed crowns, increment is good even on large yellow pines.

(2) The effect of unthriftiness in retarding growth is more pronounced in young trees than in old trees.

(3) The volumes of the various diameter classes comprising the stand, when plotted, approach the form of a smooth curve in greater or less degree, depending upon the size of the area on which the data are based. Distribution is more irregular on small areas than on large areas. Small areas can not, therefore, be depended upon for reliable stand data.

(4) The distribution of increment is similar to the distribution of volume, that is, a more or less gradual rise from the 4-inch to the

22-inch diameter class occurs and then a dropping off again in the higher diameter classes.

(5) Mortality is greatest in the higher diameter classes, in some classes affecting a net loss instead of a net increment. The greatest volume of mortality is caused by wind, but mistletoe and insects are also responsible for considerable loss. The percentage of mortality is in inverse ratio to the volume the stand reserved.

(6) Increment per cent gives no indication of volume increment per acre. Two acres may have the same growth per cent but their total absolute increment may be entirely different. The use of increment per cent is, therefore, limited to individual diameter classes and only in this way can the data obtained from one area be applied to determine the increment on other areas.

A METHOD OF PREPARING TIMBER-YIELD TABLES[1]

By DONALD BRUCE

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INTRODUCTION

On of the most comprehensive studies of the timber yields of forest stands ever attempted in the United States is that now nearing completion in the southern pines, involving four different species. These species are the longleaf pine (*Pinus palustris*), shortleaf pine (*P. echinata*), loblolly (*P. taeda*), and slash pine (*P. caribaea*)—the principal timber species of the Southern States. The field data have been collected in 10 different States, by parties under the direction of the Southern Forest Experiment Station of the Forest Service of the United States Department of Agriculture, with the cooperation of interested timberland owners, the States, and private organizations.

The importance of the work has prompted special study of the technique of preparing the yield tables, in which many features were developed that probably will be applicable to other species and in other regions. Indeed, they have already been successfully used elsewhere in one or two instances by investigators who had an opportunity to review personally the work with the southern pines. The following description is intended to make the study available to other foresters. The illustrative charts are for loblolly pine unless otherwise stated.

COMPUTATION OF FIELD SHEETS

This phase of the work needs little explanation. The values computed are obvious from subsequent paragraphs. The points on which doubt might arise were settled as follows:

A. The average diameter breast high was calculated by dividing the sum of the basal areas by the number of trees.

B. A height–diameter curve was prepared for each plot.

C. The average height corresponding to this average diameter breast high was read from the height–diameter curve.

D. The heights of subordinate species were taken from the curve for the principal species. This was necessitated by the failure of the field collectors to obtain heights except on the one principal species on each plot. The error involved is slight, however, because the plots were nearly pure, i. e., practically of one species.

E. The subordinate species which were present only in minor quantities were included in all averages and totals.

SITE-CLASSIFICATION CURVES

The first step in the analysis demanded the preparation of height-over-age curves. What was desired was not a set of growth curves for individual trees, but rather curves showing the progress (with age)

[1] Received for publication Sept. 30, 1925; issued March, 1926.

of the average height of the dominant stand. Stem analyses could not be used for this purpose with accuracy, since the number of dominant trees per acre varies with age. The average height of dominants and total age of each plot were used as the basic data for these curves. If these are plotted, a comet-shaped belt results, the edges of which are ill defined, making it somewhat difficult to divide it into site-class zones. This, however, was easily handled by anamorphosis, as follows: (1) The average height in each age class was computed; (2) these values were curved; (3) this curve was used as an anamorphic graduation curve (see fig. 1); (4) straight lines radiating from the origin were passed through the even 10-foot ordinates measured on the abscissa representing 50 years, the age arbitrarily selected as the basis for site classification. The method of locating the controlling points on these lines is indicated in the figure by a broken line, which starts from 50 years on the lower vertical scale, goes horizontally to the graduating curve, and thence vertically to intersections with the appropriate projections from the upper vertical scale. (5) For convenience these straight lines were then replotted on a system of regular horizontal graduations, thus giving a set of curves in the conventional form.

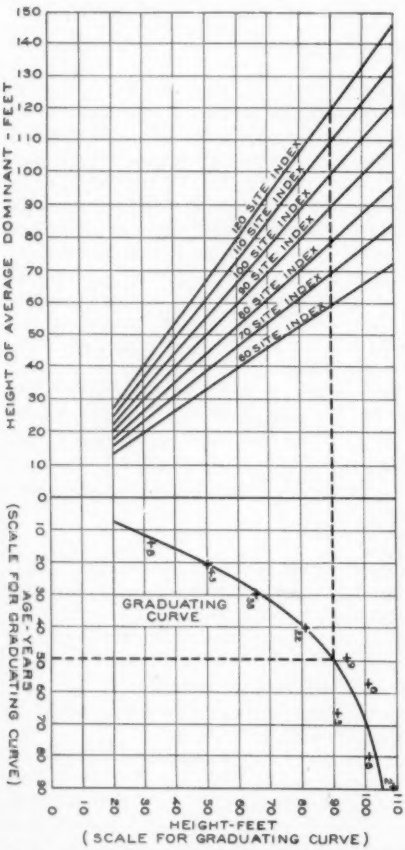

FIG. 1.—The site-index curves in anamorphic form, showing the use of the composite height-age curve as a graduating curve

SITE CLASSIFICATION OF PLOTS

The conventional conception of site classes was completely abandoned, and instead each plot was assigned a site-index number. This number was the height which the average dominant would attain (or had attained) at 50 years, read to the nearest foot by interpolation from the curves just described.

REJECTION OF PLOTS

As the basis for rejection was to be primarily basal area, it was next necessary to prepare preliminary curves of basal area over age. The anamorphic principle was again used, the successive steps being

as follows: (1) A composite curve of average basal area per acre over age for all sites combined was prepared; (2) this curve was used as a graduating curve of an anamorphic graph; (3) averages were next

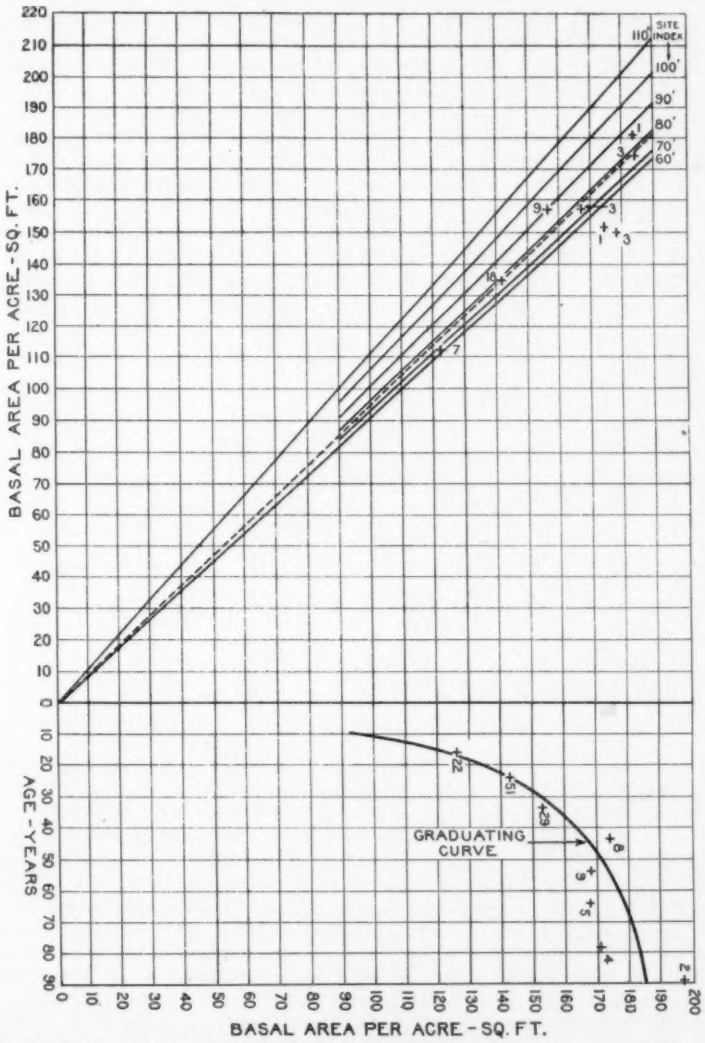

FIG. 2.—Basal area per acre, showing graduating curve and final position of radiants. Points indicated by crosses are those for 80–89 foot site-index class. Broken line through these points has average site index of 87 feet, and weight of 44

obtained by 10-year age classes for all plots, the site indices of which were from 30 to 39, 40 to 49, etc., and these averages for each "site-index class" were plotted on the anamorphic graph. Through each

series of points thus determined a straight line passing through the origin was fitted. These straight lines were carefully checked to see the sums of the positive and negative deviations (weighted) of the points from the lines were equal. The stronger site classes were handled quite satisfactorily by this process, but the weaker sometimes contained only two or three plots and were often almost absurdly erratic. Figure 2 illustrates this step, and shows the composite *basal area–age* curve used as a graduating curve. To avoid complexity the points for but a single site-index class (80–89 feet) are entered, and the broken straight line fitted thereto is shown. There would be as many other series of points and lines as there were site-index classes. (4) The spacing between these lines was then adjusted by reading the values of the intercepts on any convenient vertical graduation and then curving these values. In curving, these intercepts were plotted over the average site index represented, and were weighted by the number of plots; Figure 3 illustrates this stage. The point weighted 44 is that derived from the broken line of Figure 2. (5) The final positions of the radiants were then determined

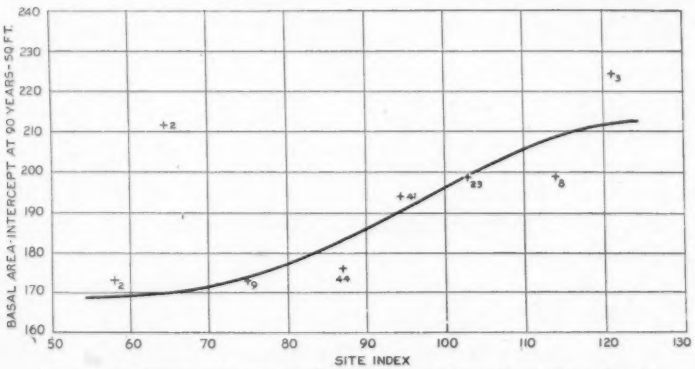

FIG. 3.—The intercept curve, used to adjust the spacing between the radiants of Figure 2

from this intercept curve, which was read at even 10-foot site-index intervals. These radiants are shown on Figure 2. Subordinate lines might be inserted at 5-foot intervals to facilitate interpolation. (6) For each plot a value for the basal area was taken from the graph (fig. 2), interpolated to the nearest year of age and nearest foot of site index. The percentages of deviation of the actual plot basal areas from those taken from the curves were then computed, using the latter as the base. The resulting values represent deviations which are practically free from the exaggerating influence of broad site and age classes. (7) The frequency distribution of these deviations was then plotted and found to be approximately normal. (8) The average deviation was computed, and the standard deviation was obtained by the approximation formula $S.\ D. = 1.25\ A.\ D.$ (9) All plots with deviations exceeding twice the standard deviation were discarded. This line was not drawn rigidly, but plots with deviations close to this value were carefully examined and retained or rejected, depending upon whether there was other evidence that they were unsatisfactory. These criteria permitted the retention of

plots which varied about 40 per cent from the curves. This very high value was due in part to the fact that several different collectors collected the field data, each collector using his own standard of normality; but it was not felt advisable to adopt a closer criterion, for to do so would have resulted in reducing the number of plots excessively. Nearly 10 per cent were eliminated by the criterion of two times the standard deviation; whereas 5 per cent would have been expected on purely theoretical grounds.

BASIC TABLE FOR ENTIRE STAND

The first step in preparing the basic table was a repetition of that just described (i. e., a preparation of curves by anamorphosis of basal area over age), but using the reduced number of plots.

The next step was a similar procedure for number of trees per acre. Anamorphosis was again used. The use of the composite *number of trees–age* curve as a graduating curve reverses the direction of the horizontal graduations read therefrom and makes the final straight lines radiate from the origin. (See fig. 4.)

The next step was a repetition of this process for diameter breast high. In this, however, it was found necessary to substitute curves of average basal area per tree, translating the results into diameter after the graphical work was completed. Furthermore, the average basal areas per tree calculated for the individual plots were not averaged together in computing the average for a site-age class. Instead, the total basal area for the class was divided by the total number of trees.[2] In order to give each plot equal weight, the values were put on a per acre basis before combining.

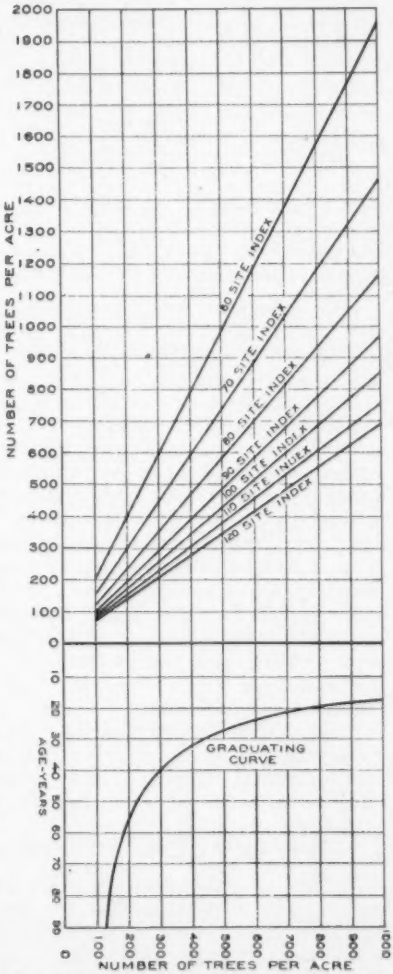

FIG. 4.—Anamorphosed number of trees per acre curves. Note apparent reversal of slope of lines resulting from use of graduating curve

The reason for these variations from the more normal procedure was that certain checks, hereafter to be described, are unsatisfactory if this precaution is not taken. A slight error is inevitable in curving

[2] This refinement was developed by Walter H. Meyer, of the Northeastern Forest Experiment Station.

average diameters which have been averaged by basal area. The drawing of the curve is itself an averaging process but in its nature is an averaging by diameter instead of by basal area. The result is therefore hybrid. There is also an error involved in averaging any averages, because the weightings are incorrect. For example, let us assume the following two 1-acre plots and note the inconsistency in the last line:

Data	Number of trees	Basal area per acre	Average basal area per tree
Plot 1	100	200	2.00
Plot 2	200	100	.50
Total	300	300	2.50
Average	150	150	1.25

The curves for cubic volume and average height [3] were prepared in a similar manner, still using anamorphosis.

These five sets of curves were then carefully checked against each other through the following relations:

A. Number of trees per acre times average basal area per tree equals basal area per acre.

B. Number of trees per acre times volume from volume table corresponding to average diameter breast high and height equals volume per acre. This checking was much simplified by the use of anamorphosis, for this permitted a check first on the composite (or graduating) curves for all sites, thus insuring the best possible fit and interrelation between the curve forms, and later a similar check on the intercept curves. Time is saved if the former are prepared for all the factors and checked against each other before proceeding further with any of the graphs. Any discrepancies discovered resulted in a readjustment of these curves, the changes being made in those which were least well defined or where the basic points seemed to permit them.

Lastly, after tables had been read from each set of curves, the values were replotted in the conventional form. This both checked computational blunders and permitted smoothing off of minor irregularities.

TABLES OF STAND 7 INCHES AND OVER IN DIAMETER

At first an effort was made to prepare these curves in a manner similar to that just described for the entire stand. The curves were, however, distorted by the use of the fixed diameter limit, and anamorphosis proved impossible. An attempt was then made to anamorphose the percentage ratios between the entire stand and that portion 7 inches and over. This was somewhat more satisfactory but not entirely so. Finally, investigations made in connection with stand tables, described later, led to the conclusion that these percentage

[3] In averaging average heights there is obviously an error similar to that just mentioned in the case of diameters. It is, however, both less serious and more difficult to avoid, and this slight discrepancy was accepted.

relations should be a function of diameter breast high alone and independent of height and age. This hypothesis was checked directly, by plotting the percentages over each of these three variables in turn, and found to be true. Curves were therefore prepared as follows: (1) The actual difference between the average diameters breast high of trees 7 inches and over and of the entire stand, over the latter; (2) the percentage of the entire basal area in trees 7 inches plus, over diameter breast high of the entire stand; (3) the percentage of the entire number of trees represented by trees 7 inches plus, over the diameter breast high of the entire stand; (4) the board-foot cubic-foot ratio in trees 7 inches plus, over the diameter breast high of the entire stand. All of these curves were well defined. The second and third are illustrated in Figure 5.

From curve 1 the 7 inch and over table of diameters could be read by adding the curved values to those of the diameter breast high of the entire stand. For the other three it was first necessary to prepare, by reference to the basic table of diameters breast high

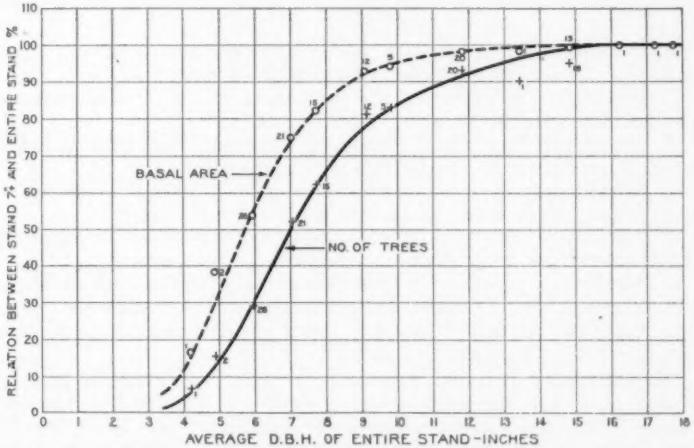

FIG. 5.—Two of four curves used in deriving tables for stand 7 inches plus from those for entire stand

for the entire stand, tables of percentage ratios (or board-foot cubic-foot ratios in the last case) for the site-age classes. The values of these tables multiplied by appropriate values from the entire stand tables readily yielded the desired tables of basal area, number of trees, and board-foot volume for the stand 7 inches and over.

The cross checking of these results was accomplished for the most part by checking the first three curves based on diameter breast high against each other, as follows: Increase in average basal area per tree indicated by curve 1, for each inch class, equals corresponding percentage from curve 2, divided by corresponding percentage from curve 3. The fourth curve (board feet) was checked later by comparison with the similar curve for the dominant stand.

The final tables were also replotted in conventional form, as in the case of the entire stand and for the same reason.

TABLES FOR STAND 4 INCHES AND OVER IN DIAMETER

These tables were prepared exactly as were those just described, the only difference being that there was no board-measure table, but a table of volume in cubic feet instead. The curve for this was percentage of volume 4 inches and more, over average diameter breast high of stand. Since the average height of trees 4 inches and over in diameter had not been computed, this curve could not be checked, but it was so strongly defined as apparently to be quite safe.

TABLES FOR DOMINANT STAND

Efforts to prepare these tables independently led into excessive difficulties. Analysis showed that this was caused by discrepant conceptions among the several field parties as to what constituted a dominant tree. As one party was believed to have been the most reliable and had collected considerable data, it was decided to derive the dominant tables from those for the entire stand by using percentage reduction factors based on the work of this party alone.

The following curves were prepared, on the basis of these limited data:

1. Difference in height (in feet) between dominant and entire stand, over average diameter breast high of entire stand.
2. Difference between average diameters breast high of dominant stand and of entire stand, over the latter.
3. Percentage relation in basal area between dominant and entire stand, over diameter breast high of entire stand.
4. Percentage relation in number of trees between dominant and entire stand, over diameter breast high of entire stand.
5. Percentage relation in cubic-foot volume between dominant and entire stand, over diameter breast high of entire stand.
6. Percentage relation in board-foot volume between dominant and entire stand, over diameter breast high of entire stand.
7. Ratio of board feet to cubic feet for the dominant stand, over diameter breast high of entire stand.

The values of the first five of these curves, combined with the proper tables for the entire stand, give the tables for the dominant stand. The values from curve 7 are multiplied by those resulting from curve 5. Curve 6 was of use in checking only. Curves 2, 3, 4, and 5 are illustrated in Figure 6.

The checking of these tables was quite similar to that for the 7-inches-plus tables already described except or that in board-foot volume, which was checked by comparing curve 7 with the corresponding ratio for the stand 7 inches and over by means of curves 2 and 6.

TABULAR DEVIATIONS

For a number of important items the deviations of the individual plots from the tables were computed. These were calculated in the same way as were the basal-area deviations which were used in rejecting abnormal plots, the values in all cases being interpolated to the nearest year of age and foot of site index by reading from the curves. The items for which deviations were calculated were:

Total stand.—Number of trees, basal area, diameter breast high.

Stand, 4 inches and over.—Cubic-foot volume.

Stand, 7 inches and over.—Board-foot volume (International).

From these the average deviations for the entire mass of data were computed. It was anticipated that their chief utility would be in analyzing the effect of density on various factors of yield and the influence of plot size thereon. Only the latter of the two lines of investigation proved productive, as will be described later. Average deviations rather than standard deviations were used, because the purpose for which they were intended did not seem to justify the great labor involved in calculating the latter. This seemed permissible, particularly because the frequency distribution appeared to be approximately normal.

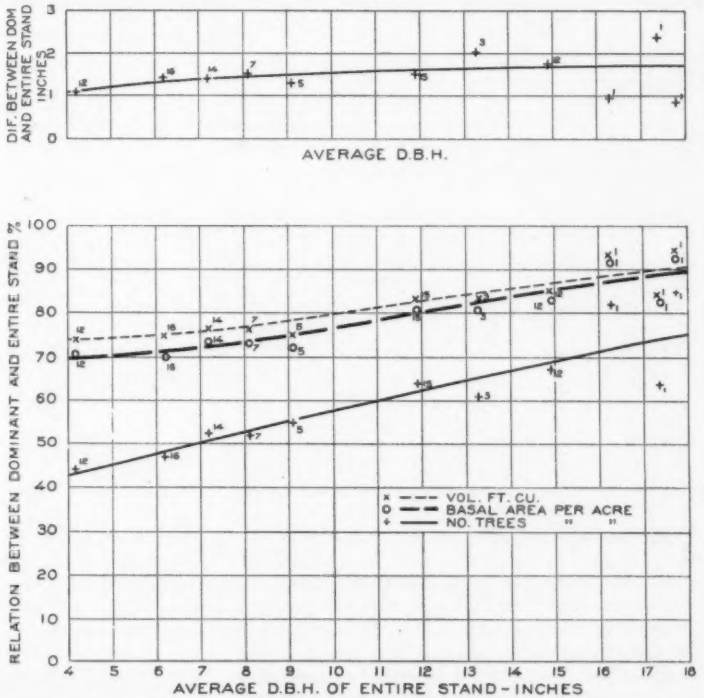
DIF. BETWEEN DOM AND ENTIRE STAND INCHES
AVERAGE D.B.H.
RELATION BETWEEN DOMINANT AND ENTIRE STAND %
AVERAGE D.B.H. OF ENTIRE STAND - INCHES
VOL. FT. CU.
BASAL AREA PER ACRE
NO. TREES

FIG. 6.—Four of curves used in deriving table for dominant stand from that for entire stand

A SUBSTITUTE FOR STAND TABLES

The desirability of stand tables to supplement yield tables is self-evident. Yield tables merely state average diameters for each age-site class. For many forest problems additional information concerning the range of diameters for each class and the distribution of the trees within this range is needed. But while the need of stand tables is obvious, preparation of them is attended by many difficulties, among which are:

1. Few age-site classes contain enough plots to give reliable stand tables.
2. Large inconsistencies develop between adjacent sites and ages.

3. Harmonization by cross curving is very complex and leads to inaccuracies.
4. The final tables would be so numerous as to be confusing and difficult to use.

For these reasons a complete set of stand tables is virtually unknown to American forestry; at most only two or three representative tables have been prepared.

The problem was therefore attacked from the more fundamental point of view suggested by F. S. Baker,[4] whose thesis is that the distribution of diameters in even-age stands follows the law of normal frequency distribution. This analysis was facilitated by the use of

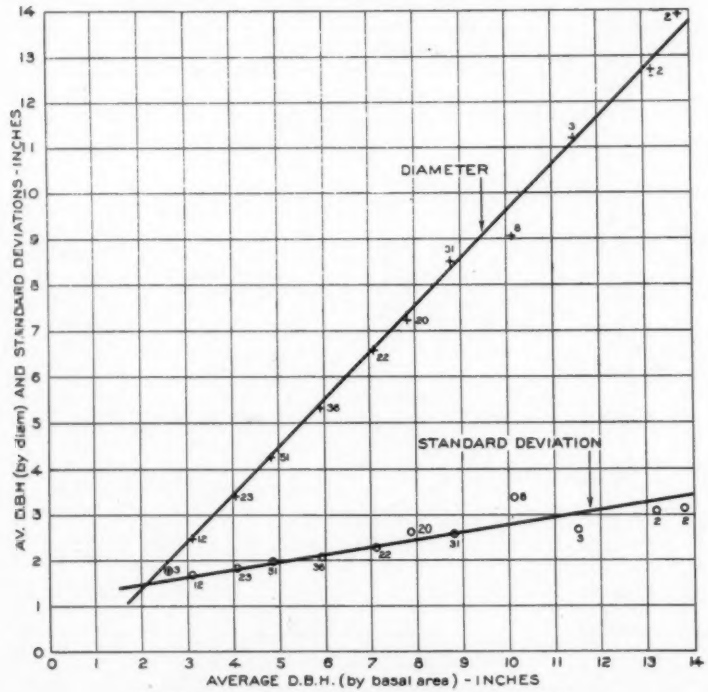

FIG. 7.—Two curves which replace stand tables. Longleaf pine

"frequency coordinate paper," (fig. 7) which is so graduated that normal frequency curves expressed cumulatively on a percentage basis are rectified into straight lines.

The successive steps were as follows: (1) Composite stand tables were prepared for each 10-year age–10-foot site-index class. (2) Each of these was expressed on a percentage basis, cumulatively; i. e., per cent of number of trees up to 3 inches, 4 inches, 5 inches, etc. (3) Each was plotted on frequency paper. The fact that straight lines could readily be fitted to the stronger classes indicated that the

[4] BAKER, F. S. NOTES ON THE COMPOSITION OF EVEN-AGED STANDS. Jour. Forestry 21: 712-717, illus., 1923.

distribution was normal.[5] (4) Diameters were read on each line at 50 per cent and 84 per cent, the former being the position of the arithmetic average and the latter that of the arithmetic average plus the standard deviation. Averages and standard deviations were thus obtained graphically for each stand table. (5) Both of these values were plotted over average diameter breast high (by basal area). Well-defined curves (straight lines in the case of longleaf) were suggested thereby and drawn in (fig. 8).

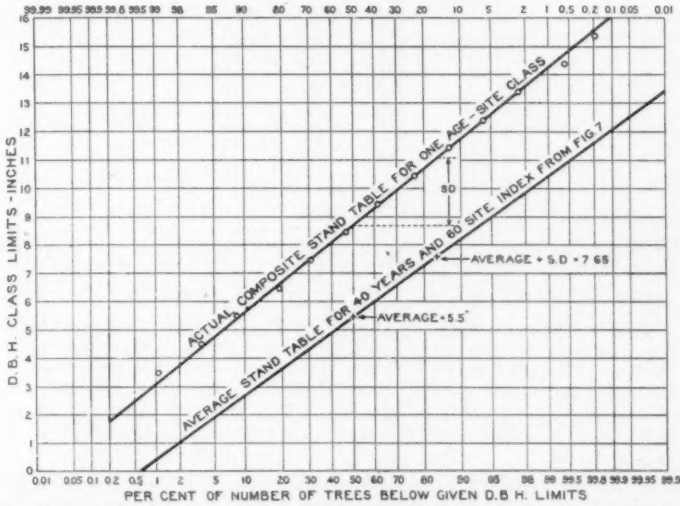
D.B.H. CLASS LIMITS - INCHES
PER CENT OF NUMBER OF TREES BELOW GIVEN D.B.H. LIMITS
ACTUAL COMPOSITE STAND TABLE FOR ONE AGE - SITE CLASS
AVERAGE STAND TABLE FOR 40 YEARS AND 60' SITE INDEX FROM FIG. 7
AVERAGE = 5.5"
AVERAGE + S.D. = 7.65
S.D.

FIG. 8.—Stand tables on frequency paper. Upper line shows use of the paper to determine average and standard deviation. Lower line illustrates derivation of complete stand tables from these two values

To illustrate the use of these graphs, let a definite problem be assumed. Suppose we wish to know how many trees over 8 inches may be expected in a stand 40 years old with a 60-foot site index. From the yield table it is found for this age and site that the average diameter breast high (by basal area) is 6 inches and the number of trees per acre is 580. Turning to the Figure 8, the corresponding diameter breast high (by diameters) is 5.5 inches and the standard deviation is 2.15 inches. To use these figures, a table of values based on the equation of the law of normal error is needed. This, in abridged form, is shown in Table I.

[5] In some other species the frequency curve seems to be skewed, but in such a way that it can be rectified on logarithmic frequency paper (which is also obtainable). The use of this is entirely parallel to that herein illustrated.

TABLE I.—*Proportion of trees deviating from the average diameter breast high by more than stated multiples of standard deviation*

Multiple of standard deviation	Trees deviating	Multiple of standard deviation	Trees deviating
	Per cent		*Per cent*
0.1	46.0	1.6	5.0
.2	42.0	1.7	4.0
.3	38.0	1.8	4.0
.4	35.0	1.9	3.0
.5	31.0	2.0	2.0
.6	27.0	2.1	2.0
.7	24.9	2.2	1.0
.8	21.0	2.3	1.0
.9	18.0	2.4	1.0
1.0	16.0	2.5	1.0
1.1	14.0	2.6	.5
1.2	12.0	2.7	.4
1.3	10.0	2.8	.3
1.4	8.0	2.9	.2
1.5	7.0	3.0	.1

The computation is as follows:

Difference between the 8-inch diameter limit and the average diameter breast high (by diameter) is $8-5.5=2.5$ inches. This difference expressed as a multiple of the standard deviation is $\frac{2.5}{2.15}=1.16$. Opposite 1.16, if shown in Table I, would be found 13 per cent. Thirteen per cent of the number of trees is $0.13\times 580=75$; therefore 75 trees per acre greater than 8 inches may be expected. When the diameter limit is less than the average, the percentage obtained is subtracted from 100 and the difference multiplied by the number of trees.

A complete stand table can be worked out by this method, but where this is desired much time can be saved by the use of the frequency paper. For the same site and age class the process is illustrated by Figure 7 and the following computation.

The values are taken from Figure 8 as before. On Figure 7 a point is located on the 50 per cent ordinate to represent the average diameter breast high, 5.5. From Table I it will be seen that 16 per cent of the values lie beyond the standard deviation or, in other words, that 84 per cent of them lie below the average plus the standard deviation, or in the present instance, below the $5.5+2.15=7.65$ inches. A second point is therefore plotted on the 84 per cent ordinate at 7.65 inches. A straight line is drawn through these two points. (See lower line, fig. 7.) The intersection of this line with the 1.5, 2.5, etc., ordinates therefore gives the percentage of the total number of trees below these limits.

The computation then proceeds as follows:

Diameter breast high class	Upper limit of diameter breast high class	Trees below upper limit	Trees within diameter breast high class	Trees in each class
Inches	*Inches*	*Per cent*	*Per cent*	*Number*
1	1.5	3	3	17
2	2.5	8	5	29
3	3.5	18	10	58
4	4.5	32	14	81
5	5.5	50	18	104
6	6.5	68	18	104
7	7.5	82	14	81
8	8.5	92	10	58
9	9.5	97	5	29
10	10.5	99	2	12
11	11.5	100	1	6

In this computation column 3 is read from Figure 7. The values in column 4 are computed by subtracting each value in column 3 from that below it. Those in column 5 are the product of those in column 4 and the total number of trees per acre, or 580, and this is the required stand table.

This resulting stand table can be checked reasonably well by means of the yield tables for trees 7 inches and over and 4 inches and over. Such a check on the example just shown gives the following results:

Method	Basal area			Number of trees	
	Total	4 inches +	7 inches +	4 inches +	7 inches +
By yield tables	108	104	65	475	185
By stand tables	110	107	65	475	185

The results are surprisingly close and seem to indicate that stand tables prepared in this manner are reliable.

It should be noted that the standard deviations used are those for composite stand tables based on a combination of all the plots of approximately equal age and site index. Theoretically, at least, the standard deviations thus obtained should be somewhat larger than those for individual plots because the composite represents a wider range of density. This result, however, should make the stand tables more applicable to stands actually to be encountered over considerable areas, even under forest management.

EFFECT OF PLOT AREA ON YIELD

The areas of the plots for one species varied from 0.05 acre to 1 acre, as illustrated by the following data, which include the rejected plots:

Plot area in acres	Number of plots	Plot area in acres	Number of plots
0.09	10	0.70–.79	3
0.10–.19	86	.80–.89	0
.20–.29	78	.90–.99	1
.30–.39	16	1.00	4
.40–.49	11		228
.50–.59	13		
.60–.69	6		

The average size is 0.24 acre, which agrees closely with that for some other yield studies, particularly those for redwood and Sierra western yellow pine.

The 96 plots under 0.2 acre in size averaged 6 per cent above all the plots in basal area. This might be interpreted in two ways: (1) That there had been a tendency to locate the plot boundaries too close, or (2) that the effort to get plots as large as possible resulted in the inclusion of occasional holes in those of greater area. A personal examination of a considerable number of the plots leads the writer to believe the latter to be the more probable explanation.

The question of proper plot area is in need of more thorough analysis. The general impression has been that plots should be as large as possible without too great a sacrifice in density of stocking, and that smaller plots are permissible in younger stands. In some studies limits of 0.1 to 1 acre have been set. It seems possible that a limitation by area is illogical and that a limitation by number of trees should be substituted. The average number of trees per plot in the longleaf study was 157. On the basis of the composite curve for all sites showing number of trees per acre this corresponds to the following area scale:

Age	Area per plot in acres	Age	Area per plot in acres
10	0.09	60	0.46
20	.14	70	.52
30	.22	80	.60
40	.31	90	.67
50	.39	100	.71

If the average numbers of trees per plot as actually collected be curved over age, it is found that the men collecting field data came surprisingly close to this scale. If the idea of a limitation by numbers is sound, however, it appears that the most dubious plots were not the smallest (0.05 acre at 15 years) but plots about 65 years old with an area of 0.15 acre. If the conception is explicit and consciously followed, it seems that improved plot selection may be expected. Of course, any standard should be somewhat flexible, and the writer would suggest a range of 100–200 trees per plot.

ADVANTAGES AND DISADVANTAGES OF METHODS USED

Probably the chief criticism which may be raised against the method is in connection with the use of anamorphosis. As applied it produces curves of the same shape for each site-index class. A typical result of this similarity is that the mean annual and current annual growth culminate at the same age for all sites. This is contrary to the accepted idea of what is to be expected. Before condemning the method on this account it is well, however, to consider the alternative. In the conventional technique in which a zone of points is plotted and then divided into three or five subzones there is normally a concentration of points toward the central portion of the range, the very old and very young plots being relatively scarce. This concentration will tend to make the zone bulge near the middle, and this distortion will in turn tend to increase the curvature of the curves for the higher sites and decrease it for the lower. This results in an apparently earlier culmination for the former, and sometimes in the complete obliteration of culmination for the latter.

It is not necessary to claim that this tendency is the fundamental and exclusive reason for belief in the law of early culmination of mean annual growth on good sites. Very probably there is a difference in their favor, but this difference is almost surely less marked than many yield tables would indicate. Choice must be made, then, between two methods, one of which disregards and the other exaggerates this tendency.

It should be noted, moreover, that where anamorphosis is forcing the curves into too rigid a mold, this fact should be evidenced by a consistent deviation of the trend of the points from the radiant straight-line form. In no one of the four southern pine species studied was this apparent. It therefore seems clear that the tendency was too slight to be made manifest by the number of plots investigated (from 100 to 250). It should also be noted that this rigidity resulting from anamorphosis is associated only with the tables for the entire stand. Those for trees 4 inches and over, and 7 inches and over, and for the dominant stand, may all culminate at variable ages.

The chief advantages of the method, on the other hand, are the free use of a number of the conceptions of modern statistical technique and the careful cross checking of all the results obtained. This, it is felt, should produce a satisfactory yield table at a minimum expense, because the greatest accuracy possible is obtained from a small number of plots.

CHROMOSOMES AND THEIR SIGNIFICANCE IN STRAWBERRY CLASSIFICATION[1]

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INTRODUCTION

Strawberry breeding has received the consideration of horticulturists for the last century. Each year many new varieties appear on the market, but from these only a small number persist and the majority are discarded. A factor that has caused much of the work of the breeder to be discarded has been the character and behavior of sex as found in this genus.

The variability so general in some species of Fragaria led the writer to undertake a study of the chromosomes of this group. This report of the chromosome number in Fragaria is not complete, but it includes the results of a study of all the material readily available to the writer in the last two years. Cummings and Jenkins (*4*)[2] consider recent or latent hybridity as one of the probable causes of the polymorphism that characterizes Fragaria species. The same writers conclude that hybridity is one cause of dioeciousness as it exists in this genus.

In the genus Rosa, Täckholm (*16*), Blackburn and Harrison (*1*), and Penland (*12*) have shown that polyploidy is associated with polymorphism, and the writer has found that a similar relation exists in the genera Rubus (*9*) and Crataegus (*10*). The results from cytological studies of these closely related genera foreshadowed a possibility that some chromosome variability might be associated not only with polymorphism but with sexuality as it exists in cultivated and wild strawberries.

The species *Fragaria vesca* var. *americana alba* was chosen for reconnaissance. This variety is characterized as being perfect-flowered, and its haploid chromosome number was found to be 7. This is also the basic number for two other genera of the Rosaceae, viz. Rubus and Rosa.

Valleau (*17*) had reported for *F. virginiana* and for one garden variety a haploid chromoscme number of 26. These two very different chromosome numbers in different Fragaria species made it apparent that polyploidy exists also in this genus of the Rosaceae.

MATERIAL AND METHOD

Buds used in the determination of the haploid chromosome number in pollen mother cells of Fragaria were collected at the Bell Horticultural Experiment Station, Glenn Dale, Md. G. M. Darrow, who is in charge of the strawberry breeding work of that station, kindly provided the material and has assumed the responsibility for its identi-

[1] Received for publication July 8, 1925; issued March, 1926.

[2] Reference is made by number (italic) to "Literature cited," p 567.

fication.[3] Buds of the wild strawberry, *Fragaria virginiana*, were collected by the writer in four separate and isolated regions near Aurora Hills, Va.

The choice of forms for study was made so as to include representatives of as many distinct species as possible, and to include those horticultural varieties of outstanding genetic and economic interest.

All buds were killed, in the field, in either Bouin's chromo-acetic or acetic-absolute killing fluids. Very young buds were necessary in order to have pollen mother cells at the reduction phases, and to get them at this stage it frequently was necessary to dig them out of the crown of the plants with the point of a knife.

Buds embedded in paraffin would not cut satisfactorily unless previously treated with a 7 per cent solution of hydrofluoric acid solution for 24 hours to remove mineral crystals from the plant tissue. Buds so treated cut much more satisfactorily when embedded in Parlodion than in paraffin; the felty mass of hairs that covers young buds interferes with cutting smooth paraffin ribbons, unless the edge of the knife is wiped off carefully after every three or four cuts.

Sections from 10 to 15 μ thick gave uncut nuclei for study, and these were stained with Heidenhein's haematoxylin. Buds killed with Bouin's fluid did not stain as satisfactorily as buds killed with chromo-acetic or acetic-absolute fluids, and frequently buds treated with the former fluid could not be stained with sufficient clearness to make a count of the chromosomes at meiosis.

Toward the close of the study Belling's chromo-acetic method was tried for staining pollen mother cells, and it gave well-stained figures. If further work is carried on, this quick and reliable stain will be adopted whenever material is abundant.

The 27 Fragaria forms that have given satisfactory material for making chromosome counts fall into these three groups—diploid with 7 as the reduced number, hexaploid with 21 as the reduced number, and octoploid with 28 as the reduced number of chromosomes.

The three following sections describe and discuss some of the outstanding characteristics of these three groups.

DIPLOID FRAGARIA

Fragaria vesca var. *alpina*, hort. var. Belle de Meaux.
Fragaria vesca var. *americana alba*.
Fragaria vesca from Petrograd, Russia.
Fragaria vesca from Tiflis, Russia.

The species and forms listed above were found to have seven bivalent chromosomes at diakinesis. Koch (*8*) describes *Fragaria vesca* as a perfect-flowered species, and Hedrick (*6*) writes that "practically all English strawberries have perfect flowers." This study indicated that *F. vesca* is unique in having a haploid chromosome number of seven (fig. 1, B, C, D, G, H, J, and K), and it seems significant that it is always hermaphrodite.

The small number of haploid chromosomes made it comparatively easy to make counts, in spite of the extreme minuteness of the buds at the time pollen mother cells were undergoing meiosis.

Both heterotypic and homotypic divisions in all diploid forms seemed to be carried out in a perfectly regular manner. The small

[3] Herbarium specimens representing all materials used are being prepared and will be placed in the National Herbarium.

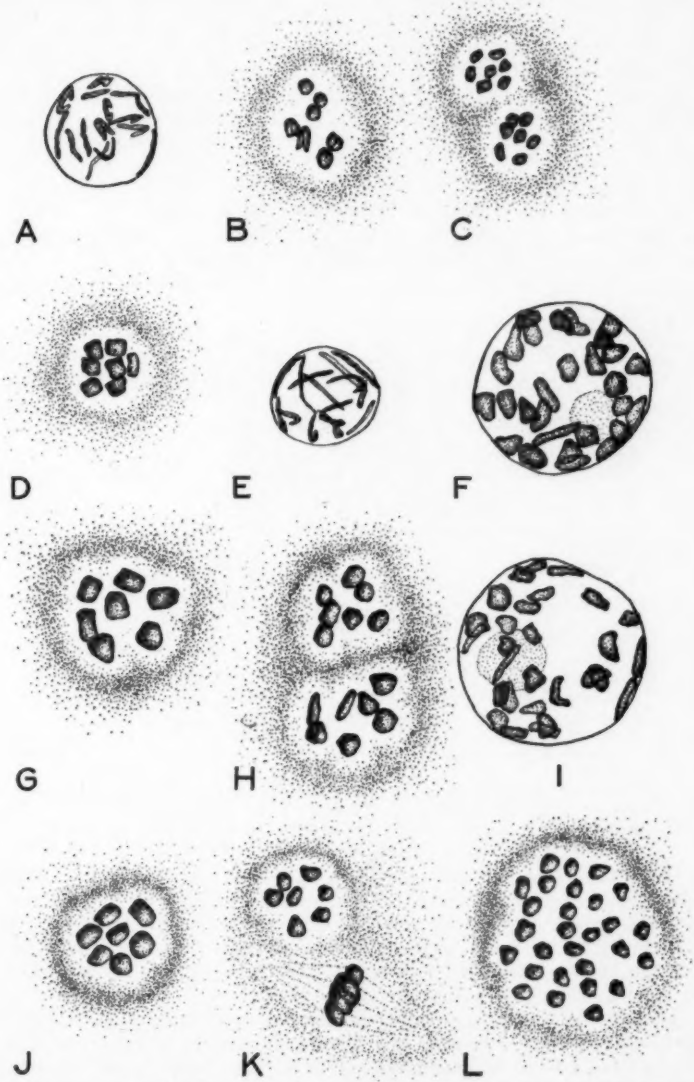

FIG. 1.—Chromosomes in Fragaria. A, Somatic chromosomes in a cell from the ovule wall of *F. vesca*. B, Heterotypic phrophase in a pollen mother cell of *F. vesca* var. *americana alba*. C, Homotypic metaphase in a pollen mother cell of *F. vesca* var. *americana alba*. D, Heterotypic metaphase in a pollen mother cell of *F. vesca*. E, Prophase in a cell from the ovule wall of *F. vesca*. F, Diakinesis in a pollen mother cell of *F. virginiana*. G, Heterotypic metaphase in a pollen mother cell of *F. vesca* var. *alpina* hort. var. Belle de Meaux. H, Homotypic metaphase in a pollen mother cell of *F. vesca* var. *alpina* hort. var. Belle de Meaux. I, Diakinesis in a pollen mother cell of *F. chiloensis* from British Columbia, Can. J, Heterotypic metaphase in a pollen mother cell of *F. vesca* hort. var. Ameliore Lapiene. K, Homotypic metaphase in a pollen mother cell of *F. vesca* hort. var. Ameliore Papiene. L, Heterotypic metaphase in a pollen mother cell of *F.* (hybrid?) hort. var. Harcourt de Thuey.

(The drawings A, G, and H were made with the aid of a camera lucida, using a 1/16 Leitz apochromatic objective, an × 18 ocular. The drawing paper was pinned to the table, on a level with the base of the microscope. G, H, and L drawn from aceto-carmine preparations. All reduced 1/3 in reproduction).

size of the elements caused the writer to confine his attention mainly to chromosome number, and to their distribution in the formation of the pollen tetrad, omitting a study of the important phases prior to diakinesis. The somatic chromosome number of 14 was observed frequently in the cells of the ovule wall. This condition is shown in Figure 1, A and E, for two varieties of *Fragaria vesca*.

HEXAPLOID FRAGARIA

Fragaria elatior hort. var. Royal-Hautbois.
Fragaria elatior hort. var. Monstreus-Hautbois.

The two above varieties of *Fragaria elatior* were found to have 21 as the reduced chromosome number. Figures 2, H and I, shows the chromosomes at diakinesis and at the heterotypic metaphase, respectively.

This species is described by Koch (*8*) as "Unvollkommen zweihäusig" and so *Fragaria elatior* differs from the diploid Fragaria in having a higher chromosome number and in being frequently dioecious.

OCTOPLOID FRAGARIA

Fragaria chiloensis from Alaska.
Fragaria chiloensis from British Columbia.
Fragaria virginiana from Aurora Hills, Va.
Fragaria virginiana var. *glauca*.
Fragaria virginiana hort. var. No. 13.
Fragaria (hybrid?) hort. var. Aroma.
Fragaria (hybrid?) hort. var. Dunlap.
Fragaria (hybrid?) hort. var. Harcourt de Thuey.
Fragaria (hybrid?) hort. var. Howard No. 17.
Fragaria (hybrid?) hort. var. Klondike.
Fragaria (hybrid?) hort. var. Marshall.
Fragaria (hybrid?) hort. var. Progressive.
Fragaria (hybrid?) hort. var. Redfew.
Fragaria (hybrid?) hort. var. Rockhill No. 26.
Fragaria (hybrid?) hort. var. Royal Sovereign.
Fragaria virginiana hort. var. No. 27×*chiloensis*.
Fragaria virginiana hort. var. No. 27×(hybrid?) hort. var. Howard No. 17.
Fragaria virginiana hort. var. No. 27×(hybrid?) hort. var. Marshall.
Fragaria (hybrid?) hort. var. Howard No. 17×*chiloensis*.
Fragaria (hybrid?) hort. var. Dunlap×*virginiana* hort. var. No. 13.
Fragaria (hybrid?) hort. var. Minn. No. 82×(hybrid?) hort. var. Marshall.

The foregoing are the species and forms in which 28 bivalent chromosomes were counted at diakinesis. This number is not in agreement with the number 26 as determined by Valleau (*17*). It is possible that variations in chromosome number may sometimes occur, but the 21 varieties and forms examined by the writer usually showed 28 chromosomes at diakinesis.

Due to the large number of chromosomes in the group, and to the fact that in killed material the chromosomes are usually crowded at the metaphase plate, it has been difficult to make accurate counts. Fortunately, the chromosomes paired definitely at diakinesis and stained readily. The presence of deep staining nucleolus at this stage frequently interferes in making counts, and so in a few instances when material was scanty only 26 and 27 bivalent chromosomes could be distinguished. In view of the smallness of the units, and the possibility that one or two chromosomes might be hidden, the writer considers that in general the Fragaria species and varieties listed above have a haploid chromosome number of 28.

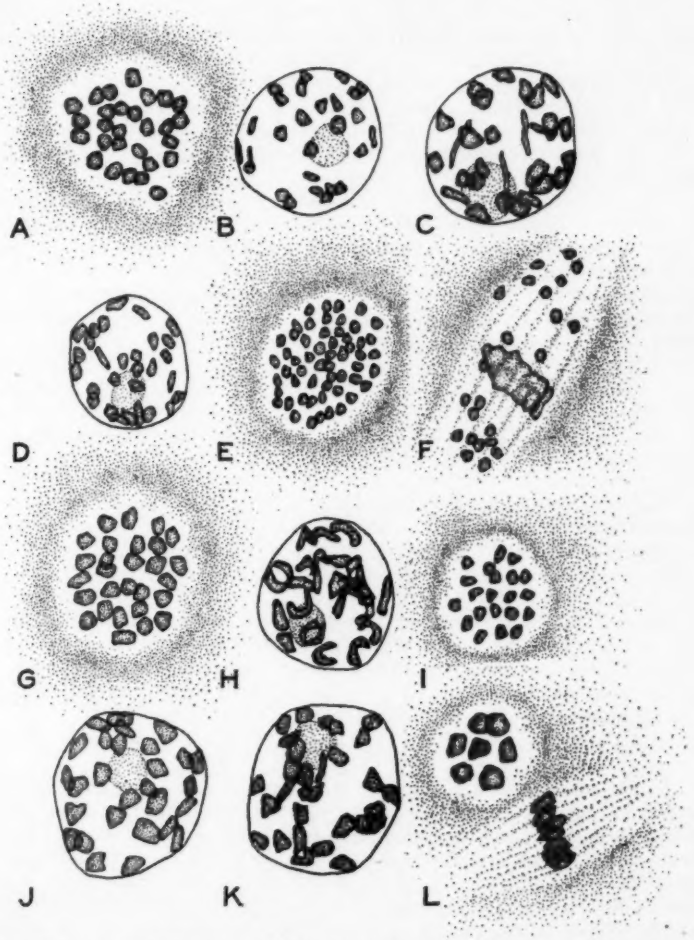

FIG. 2.—Chromosomes in Fragaria. A, Heterotypic metaphase in a pollen mother cell of *F. chiloensis* from Alaska. B, Diakinesis in a pollen mother cell of *F. virginiana* var. *glauca*. C. Diakinesis in a pollen mother cell of *F.* (hybrid ?) hort. var. Royal Sovereign. D, Diakinesis in a pollen mother cell of *F.* (hybrid ?) hort. var. Progressive. E, Abnormal heterotypic metaphase (plate view) in a pollen mother cell of *F. virginiana* hort. var. No. 27 × *chiloensis*. F, Abnormal heterotypic metaphase spindle in a pollen mother cell of *F. virginiana* hort. var. No. 27 × *chiloensis*. G, Normal heterotypic metaphase in a pollen mother cell of *F. virginiana* hort. var No. 27 × *chiloensis*. H, Diakinesis in a pollen mother cell of *F. elatior* hort. var. Monstreus-Hautbois. I, Heterotypic metaphase in a pollen mother cell of *F. elatior* hort. var. Royal-Hautbois. J, Diakinesis in a pollen mother cell of *F.* (hybrid ?) hort. var. Aroma. K, Diakinesis in a pollen mother cell of *F. vesca* var. *americana alba* × (hybrid ?) hort. var. Aroma, octoploid form. L, Homotypic metaphase in a pollen mother cell of *F. vesca* var. *americana alba* × (hybrid ?) hort. var. Aroma, diploid form.

(The drawings A, H, and L drawn from aceto-carmine preparations.)

The outstanding observation during meiosis in these octoploid forms was the regularity with which all chromosomes paired at diakinesis (fig. 1, F and I, and fig. 2, B, C, D, and J), the normal manner in which the metaphase plate is formed (fig. 1, L, and fig. 2, A), and the regular separation and movements of all chromosomes to the poles at the anaphase. The outcome of a regular heterotypic and homotypic division is an equal distribution of chromosomes to the four pollen grains from the pollen mother cells. This regular behavior seemed to be the rule in this octoploid group of Fragaria, whether the form came from wild species or highly specialized garden varieties.

The few exceptions to the regular meiosis that characterizes octoploid Fragaria occur in F_1 plants of the cross *F. chiloensis* × *F. virginiana*. Figure 2, E and F, are drawings that represent the condition in a few anthers from a bud of a plant blooming in the greenhouse in February, 1925. The abnormal environment undoubtedly exemplified the irregular behavior of the chromosomes that had been observed in material of this hybrid collected in the field the previous season. Chromosomes fail to fuse at diakinesis, and in rare cases, as in the heterotypic metaphase plate (fig. 2, E) the somatic number can be counted. The more common condition is that shown in Figure 2, F, where both univalent and bivalent chromosomes are present and the distribution of chromosomes to the daughter nuclei is irregular and meiosis is characteristically abnormal.

Somatic counts in octoploid forms of Fragaria from the material at hand were not attempted. A glance at a few clear figures showed approximately the number of chromosomes expected, but counts of so large a number in such small cells could give only uncertain figures.

Darrow (*5*) in a recent article discusses the importance of sex in the strawberry. It is from this group of high-chromosomed forms that all students of sex in Fragaria have selected their material. A more general consideration of the relation between chromosome number and sex will be left for the concluding discussion.

FALSE HYBRIDS

Thirty years ago Millardet (*11*) described some Fragaria hybrids which he considered were false, originating without the fusion of the parent nuclei. These forms carried the characters of one parent only. Such false hybrids should not be confused with matroclinous or patroclinous hybrids. In these latter forms there has been a true fusion of the hereditary elements of both parents, but the characters of one or the other are partially suppressed, resulting in a superficial resemblance to either the male or the female parent.

The present investigation included material from F_1 plants of the crosses *Fragaria vesca* var. *alpina* hort. var. Belle de Meaux × *chiloensis* and *F. vesca* var. *americana alba* × (hybrid?) hort. var. Aroma. All plants of the former cross were found to have in the reduction phases of the pollen mother cell 7 bivalent chromosomes (fig. 1, G). In material from one plant of the latter cross this low basic chromosome number also was found (fig. 2, L).

A second plant from the cross *F. vesca* var. *americana alba* × (hybrid?) hort. var. Aroma, showed at diakinesis (fig. 2, K) 28 bivalent chromosomes or the same number as its male parent (fig. 2, J).

Millardet (*11*) writes that in the majority of crosses of American Fragaria species with the two European species *vesca* and *elatior*, the F_1 plants resemble, in all characters, either the female parent or the male parent.

The usual care had been taken in making the two crosses just referred to, and the cytological findings of hybrids such as Millardet studied are new bits of evidence that in Fragaria we have clear cases of false hybridization, for the chromosome numbers of the two parents are so different that a true hybrid could be distinguished readily from either parent by its chromosome number.

The origin of the female type seems unquestionably a case of parthenogenesis, although some irregularity must have occurred in the embryo growth that doubled the chromosome number, giving a normal diploid form similar to the condition found in frogs that have been produced parthenogenetically. The octoploid Fragaria that resembles only its male parent both morphologically and cytologically seems to duplicate the conditions in the bigeneric hybrid described by Collins and Kempton (*3*) (Tripsacum × Euchlaena). They suggested two explanations for the absence of any characters of the female parent—it could be a true hybrid in which the characters of the female are masked by those of the male, or a false hybrid that originated from the male nucleus only and therefore involved none of the hereditary complex of the female parent in F_1 or subsequent generations.

The cytological proof found in Fragaria combined with the morphological studies of false hybrids furnishes strong evidence that parthenogenesis and the not-well-understood phenomenon, patrogenesis, are instrumental in the origin of false hybrids that completely resemble one or the other parent.

DISCUSSION

As stated early in this article, the problem in the mind of the writer was to investigate the number and behavior of chromosomes in pollen mother cells of representative forms of Fragaria, and in this way uncover, if possible, some underlying cause for the variability in some of our wild species and in all of our horticultural varieties of strawberries.

From a cytological as well as a morphological standpoint, *Fragaria vesca* appears to be the unique species of its genus. The writer considers it a representative of the primitive stock from which all the other Fragaria included in this study have sprung. This conclusion is based on the fact that it is perfect-flowered and has a haploid chromosome number of 7. These reasons for assigning such a position to *F. vesca* are supported by the similar primitive position given to diploid Rubi (*9*) and Rosae (*6*, *1*, *12*).

A general comparison of the three sister genera, Rosa, Rubus, and Fragaria, shows many common characters. Taxonomically, the three genera are puzzling, and none has been monographed satisfactorily. Attempts to propagate a species by seed frequently shows a breaking up of the parental characters, showing that the supposed species are really crypthybrids [Jeffrey (*7*)].

Cytologically, all three genera have a few stable species characterized by a basic chromosome number 7, and many variable species and forms that are polyploid.

The writer has found only two classes of polyploid Fragaria, one with 21 and the other with 28 chromosomes. This fact, and the fact that there is great difficulty in obtaining a cross between the diploid and polyploid groups, leads to the conclusion that the generic tree of Fragaria is now represented by the trunk and a few end branches. The genus at some time was doubtless in the condition now found in the genus Rubus, where new forms are ever appearing and where intercrossing occurs spontaneously between the many polyploid groups. The octoploid forms of the genus Fragaria now seem to be somewhat in the position Täckholm has given to the Canina Roses. He considers that in the past the Canina Roses were doubtlessly directly linked to diploid ancestors, but through some catastrophe many forms were blotted out and there has persisted to the present time the two very widely separated groups, with no intermediates to show the former ties of relationship.

The larger number of our Fragaria have 28 haploid chromosomes and it seems significant that all of our important horticultural varieties are included in this group. With this high chromosome number there is associated a variability that is well known to all students of this genus.

Blakeslee and others (*2*) have made a genetic study of tetraploid Datura. Table IV of their publication gives the expected ratios from the 25 possible combinations of allelomorphic characters. If 28-chromosomed Fragaria were to be considered as true octoploid forms, the data from breeding work on this group would be expected to conform to an even more complicated system of ratios than that from a tetraploid Datura.

Both Richardson (*13*, *14*) and Valleau (*17*) have spent years obtaining data on the genetic behavior of Fragaria. Much of their time has been devoted to a study of the expression of sex in horticultural varieties of strawberries. At this point a new question arises, is sex in strawberries controlled extrinsically or intrinsically?

Schaffner (*15*) has warned us that the problem of sex in organisms is for the physiological ecologist. Valleau (*17*), on the other hand, considers sex in Fragaria a problem that can be solved through genetic investigations. The fact that diploid Fragaria are hermaphroditic, and that sex differentiation occurs only in polyploid forms, inclines the writer to the view that sex in Fragaria is controlled from within and the effects of environment on sex is secondary in importance.

The variability that characterizes polyploid Fragaria differs very little from that characterizing polyploid Rubi, Roses, or Crataegus. In the three latter genera, variability is associated with a high chromosome number, and crossing between forms belonging to different chromosome groups seems to occur frequently. It has been suggested by the writer and others that polyploidy in Crataegus, Rubus, and Rosa is an indication of latent hybridity, and the work of Cummings and Jenkins supports the view that octoploid Fragaria are crypthybrids.

A review of taxonomic, genetic, and cytological findings in the genus Fragaria will demonstrate that variability is associated with polyploidy, which in turn may represent a latent hybridity. The time at which polyploidy originated in Fragaria seems remote, since there is little indication of hybridization between the forms belonging to the different chromosome groups described.

When cytological material from true crosses between plants with different chromosome numbers is available, the writer hopes to find some clues from the chromosome behavior of hybrids that will give an indication of the degree of relationship among these three Fragaria groups.

Owing to the high chromosome number and the crypthybrid nature of all strawberry forms in which dioeciousness has been reported, it seems doubtful that any simple explanation of sex as existing in Fragaria will be found. It may prove to be controlled by a very complicated system of duplicate factors.

SUMMARY

Fragaria species can be grouped into classes, similar to those found in other polymorphic genera of the Rosaceae, according to the number of chromosomes found at diakinesis.

The diploid group has 7 as the basic or haploid chromosome number and is represented by *Fragaria vesca* and its varieties.

The hexaploid group has 21 as its haploid chromosome number and is represented by two varieties of *Fragaria elatior*.

The octoploid group has 28 haploid chromosomes, and includes the two American species *Fragaria chiloensis* and *Fragaria virginiana* and many if not all of the outstanding horticultural varieties.

Sex or dioeciousness in the genus Fragaria is associated with a high chromosome number and its genetic behavior is in accord with what is to be expected from a duplication of chromosomes such as exists in true polyploid forms.

Cytological evidence is given which supports the genetic work of Millardet where the crosses attempted between American and European Fragaria resulted only in "hybridization without crossing, or false hybridization."

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THE DIGESTIBILITY AND ENERGY VALUES OF FEEDS FOR HORSES[1]

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INTRODUCTION

For a number of years investigations have been made at the Massachusetts Agricultural Experiment Station of the digestibility and metabolizable energy in the ordinary roughages, grains, and by-products likely to be fed to horses, especially horses intended for farm and other industrial uses. Lack of a respiration calorimeter prevented the determination of heat radiation, hence, in addition to digestion coefficients, only metabolizable energy could be determined, and the estimates for net energy were made according to the formula suggested by Zuntz.

Comparatively few digestion and metabolism studies with concentrated and coarse feeding stuffs with the horse have been made either in Europe or in this country. In a previous publication a brief review was made of the more fundamental studies on the nutrition of the horse (*7, p. 243–249*).[3] The work reported in the present paper covers a period of five consecutive seasons, beginning about November 1 and ending early in April. The work of each year is called a series.

HORSES AND APPARATUS USED

HORSES

Two relatively young horses, known as Tom and Joe, and weighing substantially 1,400 and 1,300 pounds, respectively, were used. In the fourth and fifth series another horse, Chub, was substituted for Tom. The horses were sound and vigorous, and were employed on the station farm during the working season.

STALLS

Two stalls, elevated 1 foot 9 inches above the main floor, were built for the purpose in a small building devoted exclusively to the work The building was heated artificially to about 50° F. in cold weather, and was properly ventilated. The stalls were each 4 feet 3 inches wide and 10 feet 3 inches long. The mangers for the hay and grain were built together. The hay manger was 2 feet 9 inches by 1 foot 5 inches at the top; 1 foot 10 inches deep; and 2 feet 9 inches by 5 inches at the bottom, that is, a cross section was an inverted acute triangle. The grain box was 1 foot 5 inches by 11 inches by 1 foot 2 inches deep. The manger was hinged so that it opened forward and outward into the aisle for convenience in putting in the feed. An iron grill 2 feet 4 inches extended across the stall in front, above the feed box, to prevent throwing out the hay.

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[2] Credit is due P. H. Smith and Ethel M. Bradley for considerable analytical work.

[3] Reference is made by number (italic) to "Literature cited," p. 603.

SCALES AND FEED RECEPTACLES

The horses were weighed on large platform scales of standard make. The feeds were weighed on sensitive scales to which a metric beam was attached. The hay was weighed out in three daily portions into 4-bushel baskets, and the grain into wooden measures or wooden trays.

HARNESSES

The leather parts of the harnesses were made by a local harness maker. The large bag for collecting the feces was made of fairly heavy duck. The funnel for the urine was made of rubber. The funnels were connected at the base with a rubber hose (one-half inch inside diameter), which at first ran through the floor of the stall into a 5-gallon glass jar beneath. This not working satisfactorily, the hose was run between the rear legs of the horses into the jar placed below and at the rear end of the stall, and was held in place by wire suspended from the ceiling (fig. 1). By this arrangement very little urine was lost, while the horses were allowed a limited amount of movement without disarranging the attachments.[4]

FIG. 1.—Showing the complete harness used for the recovery of the excreta

METHODS EMPLOYED

PERIODS

The experimental periods were from 15 to 21 days in length, depending on the nature of the ration and the amount of time required to change from one ration to another. The feces and urine were collected during the last eight days. The horses were fed three times daily, and during the preliminary period were turned into a yard for several hours each day. Salt was kept before them constantly.

WEIGHING THE HORSES

The horses were weighed on the first two and the last two days of the period proper in each trial, and at the same time each day in all cases.

[4] The plans for the harness, bag, funnel, and connections were made by Mr. Beals, who had full charge of the details of the experiments. He kept all records and calculated results for four series. Some of the analytical work was done and all of the calculations for the fifth series were made by Mr. Archibald, who also recalculated all of the results and was of great help in preparing them for publication.

SAMPLING AND WEIGHING FEEDS

The uncut hay and the grain were weighed out in advance. As the hay ration was weighed out a handful from each basket was placed in a sample basket. The composite sample was run through a feed cutter, mixed, subsampled, and taken in closed tin pails to the laboratory, where dry matter determinations were made and the samples prepared for chemical analysis. At each separate weighing of the grain into wooden measures a small sample was placed in a receptacle, and at the completion of the weighing the composite was mixed, subsampled, and taken to the laboratory for dry-matter determinations and further analysis. A careful record of the daily water consumption was kept.

SAMPLING AND WEIGHING EXCRETA

The canvas bags in which the feces were collected were emptied several times daily into galvanized-iron cans (17 inches in diameter and 2 feet deep) with tight-fitting covers. At the end of 24 hours the entire collection from each horse was weighed and spread out upon a clean, dry floor, quickly pulverized, and mixed. Small samples were taken here and there, and 1 per cent of the total amount was placed in a tightly-covered tin pail and taken to the laboratory, where it was partially dried in a shallow tin pan at a temperature of about 60° C. The daily samples, after drying, were weighed and mixed, and a dry-matter determination was made on the mixture, which was then ground fine and analyzed.

The funnels and hose were flushed out at the expiration of each 24 hours with 1,000 cubic centimeters of tap water (for which a correction was made). The contents of the large glass receptacle were mixed and weighed, and 1 per cent of the total was drawn off with a pipette into a glass-stoppered bottle, preserved with chloroform and kept in a cool place. At the expiration of the experimental periods, the composite urine sample was analyzed.

METHODS OF ANALYSIS

FEEDS AND FECES

For use in subsequent estimations of digestibility, complete fodder analyses were made on all samples of feed and feces, according to the methods of the Association of Official Agricultural Chemists (*3*). From the digestion coefficients obtained for crude fiber in each ration, an estimation of the excreted methane was made, using a factor from the work of Zuntz.

URINE

After careful mixing the specific gravity of the composite sample was determined, also the nitrogen by the Kjeldahl method, using a 10 cubic centimeter aliquot. Results of the latter determination were applied to a study of the nitrogen balance. Fifty grams were next used to determine total solids or dry matter, by evaporating and drying at 60° C. to constant weight. In addition, a considerable quantity was carefully concentrated at 60° to a gummy consistency and later thoroughly dried in a vacuum oven at room temperature. This was pulverized, sifted, and tightly bottled for future use.

CALORIFIC DETERMINATIONS

These were made (1½ grams of feed or feces and 1 gram of dried urine) by complete ignition under pressure in an atmosphere of oxygen. The apparatus used was an especially designed adiabatic bomb calorimeter of the Berthelot-Mahler-Kroecker type,[5] described in detail elsewhere (*4*). Results were reported in large calories per gram, after corrections were made for moisture in the samples and for the production of nitric acid in the bomb. In the case of the urine, difficulty was experienced due to hydroscopicity and weighing had to be done with the greatest possible rapidity. Perfect oxidation invariably took place, although the production of a strongly basic ash more than equalized the production of acid.

CALCULATIONS

DIGESTIBILITY

Having determined the amount and composition of dry matter in the feeds and feces, the calculation of digestibility is comparatively simple. The amount of dry matter and its components contained in the feces is deducted from the dry matter and its components contained in the feeds, the difference representing the amounts digested. The amounts digested, divided by the amounts consumed, give the coefficients of digestibility.

METABOLIZABLE ENERGY

This represents the total energy, minus that contained in the excreted feces, urine, and gases. The energy, expressed as calories, was determined in the feeds, feces, and urine by means of the bomb calorimeter already mentioned. The energy excreted in the form of methane was calculated from the amount of fiber digested, using the average figure by Lehmann, Hagemann and Zuntz (*5*) (0.7 calorie per gram of fiber digested).[6] A typical calculation of metabolizable energy is as follows:

Intake:		
(1) 10,500 grams of hay fed	grams dry matter	9, 252. 60
(2) Calories per gram		4. 26
(3) Total calories in hay fed		39, 416. 08
Excretion:		
(4) 4,913.12 grams of feces excreted	grams dry matter	4, 718. 56
(5) Calories per gram		4. 69
(6) Total calories in the feces		22, 130. 05
(7) 6,280 grams of urine excreted	grams dry matter	326. 56
(8) Calories per gram		2. 93
(9) Total calories in the urine		956. 82
(10) Fiber digested	grams	1, 261. 60
(11) Calories per gram (CH_4+H equivalent)		. 7
(12) Total calories in gases excreted		883. 12
(13) Total excretion (6)+(9)+(12)	calories	23, 969. 99
Balance:		
(14) Minus calories excreted. See (13)		23, 969. 99
(15) Metabolizable calories		15, 446. 09
(16) Metabolizable calories per kilo of hay fed		1, 471. 06

[5] Especially designed by E. B. Holland, of this station, and built by the late E. A. Thompson, of Amherst.

[6] In case of the horse, methane is produced largely in the colon and caecum, and is derived largely from fermentation of the fiber. Ruminants produce more methane than does the horse (*2, p. 635–639*).

NET ENERGY

This represents the metabolizable energy, minus the energy in the form of heat production resulting from the consumption of the feed. This loss of energy can be determined directly only by means of a respiration calorimeter. Such an apparatus not being available for this work the net energy was calculated indirectly from the metabolizable energy by using the formula suggested by Zuntz and Hagemann (*2, p. 676*) for the horse. In common with other investigators, they recognized that this loss is made up of two items. (1) Loss of heat due to increase of metabolism, and (2) energy expended in digestion, in the form of heat, and being proportional to the amount of crude fiber present in the feed. They estimated the losses for these items to be for (1) 9 per cent of the metabolizable energy (already determined as described above), and for (2) 2.65 calories for each gram of crude fiber present. Subtraction of these amounts from the metabolizable energy gives the net energy, which is the energy available for bodily maintenance and useful work. For convenience, Zuntz and Hagemann's deduction factor for crude fiber has been converted by Armsby to a "therms and pounds" basis. On this basis, the deduction to be made is 1.202 therms for each pound of crude fiber. A typical calculation, on a dry-matter basis, follows:

9,252.60 grams of hay fed		pounds	20.40
Metabolizable energy (already determined)		therms	15.446
20.40 pounds hay		do	15.446
100 pounds hay $=\frac{15.446\times 100}{20.40}$		do	75.72
Total crude fiber present		do	32.81
Deductions:			
Increase of metabolism, 9 per cent of the metabolizable energy, 75.72×0.09	6.81		
Additional for crude fiber, 1.202×32.81	39.44		
Total deductions		therms	46.25
Net energy value per 100 pounds dry matter		therms	29.47

In an average sample of hay, the net-energy value is less than half the metabolizable energy. The difference is used up in digesting the feed, and in the resulting increased heat radiation from the body.

THE RESULTS

All of the data, including daily food and water consumption, daily excreta, weight of animals, and calculation of results are on file. Only the results, with a brief discussion of each, are presented here.

ALFALFA AND TIMOTHY HAY [1]

These trials were made to determine the digestibility and energy values of the alfalfa (Table I). Hay was used as the basal ration. The daily ration consisted of 5 kilograms each of alfalfa and hay.

[1] For composition of this lot of hay and lots used subsequently in the work, see Table XXVIII.

TABLE I.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	I	5	48.35	52.62	59.48	39.93	54.87	None.	64.81	13.34
Tom	I	5	50.68	52.85	63.74	42.98	56.56	None.	71.84	19.73
Joe	II	4	49.08	37.04	65.14	41.46	54.58	None.	74.85	28.56
Tom	II	4	51.01	42.97	66.68	42.25	56.69	None.	82.36	35.39
Average			49.78	(a)	63.76	41.66	55.68	None.	73.47	(a)

(a) Not averaged.

The digestion coefficients of the mixture are very uniform, and, as the next section will show, were only slightly less than for the alfalfa alone. The net-energy value of the mixture was noticeably less in the first trial, due evidently to the higher fiber percentage of the alfalfa (39.57 as against 30.52).

ALFALFA

Two separate experiments were carried on with alfalfa fed combined with hay, as previously cited. That used in the first period was grown in New York State, was quite fine, and was said to be third cutting. The second lot was grown on the experiment station grounds.[8] Both lots were of good quality, although the latter was somewhat dusty. The composition of the two lots is given in Table II.

TABLE II.—*Composition*

Series	Period	Source	Water as fed	Dry-matter basis					
				Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
I	5	New York State.	10.88	6.96	13.11	39.57	38.63	1.73	190.97
II	4	Experiment station.	9.75	8.65	19.68	30.52	39.14	2.01	197.32

From the standpoint of chemical composition, the locally grown sample was noticeably the better of the two. The digestibility and net-energy values are given in Table III.

[8] Cutting not noted.

TABLE III.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	I	5	46.66	67.20	62.23	31.39	58.50	None.	64.74	9.43
Tom	I	5	51.38	67.63	69.13	37.31	62.33	None.	75.05	18.80
Joe	II	4	51.15	43.92	71.10	37.39	59.12	None.	74.49	29.08
Tom	II	4	55.00	53.55	73.94	37.94	63.92	None.	89.17	42.44
Average			51.05	58.08	69.10	36.01	60.97	None.	75.86	(a)
Average of six German trials (horses)			[b] 58.00	.....	73.00	46.00	70.00	14.00	.....	.....
Average with sheep (*6, p. 519*)			58.00	43.00	72.00	46.00	66.00	24.00	.....	.....
Hay (largely timothy for comparison)			47.00	26.00	44.00	43.00	53.00	.....	73.72	26.68

[a] Variations too great to warrant averaging the results. [b] Organic matter.

The digestion coefficients, although noticeably lower than those resulting from the German trials, as well as those obtained for sheep on the same station lot of alfalfa, are reasonably concordant. The protein is quite well utilized, the fiber less so. Neither bovines nor horses are able to digest the fiber in alfalfa very thoroughly. There were about the same number of therms of metabolizable energy in the two samples of alfalfa as in the five samples of coarse hay tested (76 against 74). The lack of uniformity of the net-energy values is due in part to the inability of Joe to utilize the feed as well as Tom, and also, in the writer's opinion, to the higher fiber content of the the first sample (39.57 per cent against 30.52 per cent). It is probable that the first sample was riper and the fiber somewhat more lignified, necessitating an expenditure of more energy to digest it. While the digestion coefficients for the two samples are substantially the same, they fail to indicate the final food or net-energy value of the material, assuming that the formula for net energy suggested by Zuntz and Hagemann is reasonably correct.

KANSAS RATION VERSUS SUBSTITUTE RATION

The Kansas ration (*9*), so-called, represented a combination of alfalfa, corn, and oats, and was recommended by that station and the United States Department of Agriculture, which experimented jointly for a period of 140 days with 17 artillery horses, doing what was termed rapid light draft.

It was recommended on the ground that a relatively small amount of alfalfa hay fed with a relatively large amount of corn would require a minimum amount of energy for its digestion; in addition, the alfalfa furnished the necessary protein. In view of the seemingly small amount of dry matter in the ration fed, and the apparent satisfaction obtained from it, it seemed worth while to determine its digestibility and energy value and to compare it with a substitute ration composed of hay, corn, oats, bran, and dried brewers' grains. The substitute ration was suggested because of the fact that little alfalfa is grown in Massachusetts, while English hay (timothy predominating) is the common roughage. The protein deficiency was

supplied in the form of brewers' grains. The amounts fed to determine digestibility are shown in Table IV, and were in the same proportions as those fed for work purposes. Each ration was supposed to satisfy maintenance requirements.

TABLE IV.—*Rations fed*

	Kansas ration	Substitute ration		Kansas ration	Substitute ration
	Pounds	*Pounds*		*Pounds*	*Pounds*
Alfalfa	8.25		Bran		1.21
Timothy		9.00	Brewers' grains		1.80
Corn	6.60	4.20			
Oats	1.65	2.40	Total	16.50	18.61

In Tables V and VI is given the chemical composition of the Kansas and substitute rations.

TABLE V.—*Composition of the rations*

Material	Water as fed	Dry-matter basis					
		Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
Kansas ration	13.72	4.68	13.66	19.30	58.82	3.55	201.42
Substitute ration	11.42	4.55	11.91	21.56	58.17	3.80	203.84

On the basis of chemical composition, there is little choice between the two rations. If anything, one would expect slightly better results from the Kansas ration, because of its lower fiber content.

TABLE VI.—*Digestion coefficients and energy values*

KANSAS RATION

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	I	3	59.15	49.26	76.68	0.62	75.75	47.93	98.70	67.08
Tom	I	3	67.36	54.08	79.09	24.83	80.12	59.40	118.52	84.65
Average			63.26	51.67	77.89	(a)	77.94	53.67	108.61	75.87

SUBSTITUTE RATION

Joe	I	4	48.89	8.71	64.74	20.83	60.73	25.13	88.06	54.22
Tom	I	4	57.08	20.42	66.15	36.78	66.43	44.69	97.88	63.16
Average			52.98	(a)	65.45	(a)	63.58	(a)	92.97	58.69

a Not averaged.

In the trials with both rations, as stated above, Joe showed less ability to digest than did Tom, although no outward signs of indigestion or debility were manifest. More fiber was digested in the substitute ration than in the alfalfa ration. In both cases, however, the percentage of fiber digested was noticeably less than in the combined ration of alfalfa and hay (42 per cent). The horses made better use of the Kansas ration than of the substitute ration; the dry matter in the former ration averaged 63 per cent digestible as against 53 for the substitute ration, while the metabolizable and net energy produced averaged 109 and 76 in the Kansas ration as against 93 and 59 in the substitute ration. One is therefore forced to conclude that, on the dry-matter basis, the Kansas combination should prove superior to the other in nutritional value.

The Kansas ration was fed to two horses at this station in substantially the same amounts on the basis of 1,000 pounds live weight, as in the experiments reported by the Kansas station in Table IV.

TABLE VII.—*Rations fed*

Horse	Weight	Amounts actually fed to horses			
		Alfalfa	Corn	Oats	Total
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Joe	1,310	11	9.88	2.50	23.38
Tom	1,390	12	10.50	2.75	25.25

The digestible nutrients and the metabolizable and net-energy values in the Kansas ration, as well as the nutrients contained in a like amount of the substitute ration (namely, 23.38 and 25.25 pounds), are given in Table VIII.

TABLE VIII.—*Composition of rations*

KANSAS RATION

Horse	Weight	Protein	Fiber	Extract matter	Fat	Total (fat × 2.2)	Metabolizable energy	Net energy
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Therms*	*Therms*
Joe	1,310	2.12	----------	8.98	0.35	11.87	19.91	13.53
Tom	1,390	2.36	----------	10.27	.46	13.64	25.83	18.45
Average	1,350	2.24	----------	9.63	.40	12.76	22.87	15.99

SUBSTITUTE RATION FOR COMPARISON

Joe	1,275	1.60	0.93	7.32	0.20	11.29	18.24	11.23
Tom	1,390	1.76	1.77	8.64	.38	13.01	21.90	14.13
Average	1,300	1.68	1.35	7.98	.29	12.15	20.07	12.68

In Table IX the above data are summarized, and figures from three accepted standards are also shown.

TABLE IX.—*Summary*

	Average weight of horses	Digestible nutrients and energy values						
		Protein	Fiber	Extract matter	Fat	Total	Metabolizable energy	Net energy
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Therms*	*Therms*
Kansas	1,350	2.24		9.63	0.40	12.76	22.87	15.99
Substitute	1,350	1.68	1.35	7.98	.29	12.15	20.07	12.68
Lavalard's standard	1,350	1.80				16.88		
Grandeau's standard	1,350	2.59				17.32		
Kellner's standard	1,350	2.16				19.17		

Compared on a dry-matter basis, the Kansas ration contained rather more total digestible nutrients and noticeably more metabolizable and net energy than did a like amount of the substitute ration. Compared with generally accepted standards, both the Kansas and the substitute rations were below the requirements for total digestible nutrients.

These digestion and energy values agree with practical work trials with the horses. When the Kansas ration was fed for two months in the autumn, the horses doing light work a considerable part of the time held their weights, but they seemed hungry and were very restless and quite unsatisfactory to the teamster in charge. Kansas Ration II, which represented the original ration plus 10 per cent of the grain mixture, was fed for 42 days the following spring to the same horses. They were worked lightly at first, and as the work was increased they began to show a gradual loss in weight and seemed nervous and hungry. As the season advanced the entire Ration II was increased 10 per cent, which improved their general temper, but they still seemed rather uneasy and hungry. Part of this uneasy condition may have been due to the lack of bulk in the ration.

Identical amounts of dry matter in the form of the substitute ration were not fed to the horses at work, but for a period of 28 days each horse daily received, 33 pounds of the substitute mixture, which was estimated to contain 15.5 pounds of digestible nutrients and 17.25 therms of net energy, and the conclusion at the time was that they received sufficient nutrients to keep them in normal condition and give satisfactory service.

The writer's general conclusion is that a combination of corn, oats, and alfalfa (the Kansas ration), on the basis of dry matter, furnishes more nutrients and net energy than does a like amount of a combination of timothy, corn, oats, bran, and dried brewers' grains (the substitute ration), and that such a combination is likely to prove more economical if alfalfa is cheap enough. However, it was evident both on the basis of digestible nutrients and net energy as actually determined, as well as on work performed, that the amount of the Kansas ration fed to the Army horses (6.8 pounds of corn, 1.7 pounds of oats, and 8.5 pounds of alfalfa hay per 1,000 pounds of live weight) was not sufficient for horses doing medium farm work, and that an increase of some 20 per cent over the above figures would be necessary for satisfactory results.

GROUND BARLEY AND HAY

To obtain the requisite data for the digestibility and energy values of barley, it was fed to the horses in combination with hay. The ration fed was 8 kilograms hay and 2.5 kilograms barley (Table X).

TABLE X.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	III	6	56.13	42.56	57.47	38.03	66.11	9.84	96.61	57.82
Tom	III	6	56.68	43.73	55.07	39.69	66.51	9.00	96.13	57.38
Average			56.41	43.15	56.27	38.86	66.31	9.42	96.37	57.60

GROUND BARLEY

Next to oats, barley is recognized as a very satisfactory grain for horses. It is used quite freely in Europe and California.

The average composition of its dry matter was: Ash, 2.95 per cent; protein, 12.14; fiber, 5.98; N-free extract, 76.27; fat, 2.66. Its calorific value as determined was 200.9 therms per 100 pounds.

TABLE XI.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	III	6	76.57	105.84	93.96	None.	86.25	17.25	166.27	152.36
Tom	III	6	78.94	113.98	88.26	None.	87.66	14.21	161.55	148.03
Average			77.76	109.91	91.11	None.	86.95	15.73	163.91	150.20
Oats for comparison			61.07	(a)	75.09	None.	72.21	57.05	133.04	118.20

[a] Not averaged.

The barley had a high digestibility in all constituents except fiber and fat, which are present in such small amounts as to render the results for these ingredients of uncertain value. In net energy the results in Table XI give it a higher value than any other single feed examined. Its value in comparison with other carbonaceous feeds, based on results obtained in these experiments, will be discussed further on. Its value was considerably above that for oats, due in large measure to its lower fiber content. On account of price, barley is not likely to prove an economical grain for horses in the eastern part of the country.

BREWERS' GRAINS AND HAY

Two separate lots of brewers' grains were fed, one in each of two consecutive series of experiments. The composition of the two lots is shown in Table XII.

TABLE XII.—*Composition*

Lot	Water as fed	Dry-matter basis					
		Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
I	6.77	3.41	27.94	16.06	45.65	6.94	229.52
II	8.58	3.28	29.64	15.11	45.00	6.97	229.07

The composition is seen to have been uniform. The high calorific value is worthy of mention, due to the fat present. Table XIII shows the digestibility and net-energy coefficients of the combined ration of 8 kilograms hay and 2.5 kilograms brewers' grains.

TABLE XIII.—*Digestion coefficients and energy values*

BREWERS' GRAINS AND HAY

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	5	43.40	24.27	65.07	37.62	44.96	19.57	*75.06	*32.32
Tom	II	5	47.96	28.60	66.75	42.85	49.86	24.66	*83.20	*39.73
Joe	III	3	49.70	22.00	59.09	39.98	56.35	23.86	97.09	54.73
Tom	III	3	51.17	27.32	61.03	41.30	57.17	31.47	101.85	59.06
Average			48.06	25.55	62.99	40.44	52.09	24.89	99.47	56.90

* Not included in the average.

In each of the two experiments, Joe digested less than did Tom. The two horses seemed to utilize the second ration better than the first, although the results do not show wide variations. Deducting the digestibility and energy values of the hay, as previously determined, from those of the combined ration, the results for the brewers' grains are as given in Table XIV.

TABLE XIV.—*Digestion coefficients and energy values*

BREWERS' GRAINS

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	5	[a] 32.26	15.02	79.18	[a] None.	[a] 24.68	38.59	[a] 74.58	[a] 45.60
Tom	II	5	50.93	42.49	84.09	21.99	46.02	48.61	[a] 107.04	[a] 75.19
Joe	III	3	48.03	None.	71.82	20.08	49.81	40.38	163.37	133.06
Tom	III	3	54.06	10.42	74.64	[a] 30.09	53.88	55.42	180.43	148.61
Average			51.01	([b])	77.43	27.39	49.90	45.75	171.90	140.48

[a] Not included in the average. [b] Not averaged.

In the first experiment, assuming that Joe digested the fiber and extract matter in the hay when fed in the combined ration as well as when fed by itself, it is evident that he experienced difficulty in digesting these ingredients contained in the alfalfa, and these results are excluded from the average as well as those for the metabolizable and net-energy values. The other results, excepting those for the metabolizable and net energy in case of Tom in the first experiment are about as uniform as could be expected. In each experiment the horses experienced apparent difficulty in digesting the fiber, extract matter, and fat, while they handled the protein without trouble. This is the only material investigated in which energy value (note Tom in Series II) is high when the total digestibility and fiber digestibility are relatively low. A satisfactory explanation is not apparent.

CORN AND ITS BY-PRODUCTS

Shelled corn, corn meal, corn bran, corncobs, and gluten feed were investigated. The object was to compare the digestibility of whole corn with corn meal, and likewise to obtain some definite data relative to the ability of the horse to digest the several corn by-products. Analytical data are shown in Table XV.

TABLE XV.—*Composition of corn and corn by-products*

Material	Water as fed	Dry-matter basis					
		Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
Corn (shelled)	13.40	1.38	9.88	3.03	81.58	4.13	199.58
Cracked corn [a]	15.91	1.52	10.93	1.88	80.65	5.03	200.49
Corn meal	10.81	1.54	10.09	2.59	82.13	3.65	203.67
Gluten feed [b]	9.38	4.59	28.58	6.63	57.69	2.51	214.71
Corn bran	13.03	1.12	7.54	12.15	77.86	1.33	203.21
Corncobs	18.67	1.70	3.14	30.23	64.22	.72	205.48

[a] Average of two lots. Lack of time prevented digestion and energy determinations.
[b] Average of three lots.

The tabulation of Table XV simply emphasizes the strictly carbonaceous nature and low ash content of these feeds, the one exception being gluten feed, to which a little lime was evidently added in the process of manufacture. The calorific value of each of the products was substantially the same.

It was intended to have the corn meal represent the sample of whole corn ground, but judging from the anlaysis this was not strictly the case. The writers are reasonably sure, however, that the corn meal was ground whole corn.

SHELLED CORN AND HAY

Table XVI represents the digestion coefficients and energy values of the combined ration of 8 kilograms hay and 2.5 kilograms corn.

TABLE XVI.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	7	72.28	None.	61.22	None.	86.10	13.16	87.57	47.01
Tom	II	7	76.69	37.65	62.04	None.	84.40	30.82	89.32	48.60

The results in regard to uniformity are all that could be expected.

CORN MEAL AND HAY

The digestion coefficients and energy values of the combined ration (8 kilograms hay and 2.5 kilograms corn meal) are shown in Table XVII. The results agree quite closely with those for hay and shelled corn.

TABLE XVII.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	6	73.98	18.83	84.14	None.	86.43	32.31	87.64	48.08
Tom	II	6	72.70	13.89	60.55	None.	84.99	25.28	88.27	48.74

CORN (SHELLED)

The digestibility and energy values of the shelled corn were obtained by determining the values for the hay and corn as given above and then deducting therefrom the digestibility and energy of the hay as determined in a separate experiment. (Table XVIII.)

TABLE XVIII.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	7	72.28	None.	58.95	None.	86.10	41.73	128.25	109.53
Tom	II	7	76.69	37.65	64.31	None.	84.41	59.39	134.86	115.54
Average			74.49	(a)	61.63	None.	85.26	50.56	131.56	112.54

a Not averaged.

CORN MEAL

The coefficients for the corn meal, determined in a similar way to the shelled corn, are given in Table XIX.

TABLE XIX.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	6	73.98	18.83	81.84	None.	86.43	66.13	129.80	116.18
Tom	II	6	70.68	9.96	61.39	None.	83.52	58.65	131.10	117.31
Average			72.33	(a)	71.62	None.	84.98	62.39	130.45	116.75

a Not averaged.

COMPARISON SHELLED CORN *v.* CORN MEAL

Series	Period	Dry matter	Ash	Protein	Fiber	Extract matter	Fat	Energy value per 100 pounds	
								Metabolizable	Net
								Therms	*Therms*
II	7	74.49	(?)	61.63	(?)	85.26	50.56	131.56	112.54
II	6	72.33	(?)	71.62	(?)	84.98	62.39	130.45	116.75

OATS FOR COMPARISON

II	5	61.07	(?)	75.09	(?)	72.21	57.05	133.04	118.20

The figures in Table XIX indicate that, so far as one is able to form an opinion from the results of a single trial with two horses, the animals were able to utilize the whole corn equally as well as the ground article. The net-energy values agree quite closely with those given by Armsby for dent corn (*2, p. 721*).

CORN BRAN AND HAY

Corn bran is the outer layer or skin of the corn kernel. It seldom appears as such on the market, most of it being used as an ingredient in gluten feed and other commercial feeding materials. Compared with wheat bran, it contains about half as much protein, less ash and fat, rather more fiber, and nearly 50 per cent more extract matter (Table XX). The ration fed was 8 kilograms hay and 2 kilograms corn bran.

TABLE XX.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy[a]
									Therms	*Therms*
Joe	II	2	45.23	28.19	42.66	39.06	51.51	12.48	71.91	28.30
Tom	II	2	51.42	34.40	47.06	48.19	56.15	21.03	86.69	41.75
Average			48.33	31.30	44.86	43.63	53.83	17.21	79.30	35.03

Joe was not digesting as well as Tom, both the coefficients and energy values for him being noticeably below those for Tom.

CORN BRAN

TABLE XXI.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	2	66.58	180.90	35.08	123.18	60.89	16.08	100.61	73.78
Tom	II	2	85.80	190.91	69.97	157.82	72.60	81.37	160.11	127.90
Average			76.19	185.86	(a)	140.50	66.75	(a)	(a)	(a)
Wheat bran (for comparison)[b]			51.00	16.44	83.37	65.32	45.78	(a)	69.93	52.34

[a] Not averaged.

[b] The figures given here for wheat bran are not the average results presented later in this article but are those obtained in an experiment immediately succeeding the one in which corn bran was fed. Because of the close proximity of the two experiments, they are thought to be more comparable than the average results for wheat bran, in which there is a great deal of irregularity.

The results for the corn bran are not satisfactory, the divergencies being altogether too great. Joe had a markedly negative nitrogen balance, while Tom showed a gain in nitrogen. Despite the irregularity in results, the corn bran is probably fairly well utilized by horses, and evidently it has value considerably above wheat bran as an element in the horse ration.

GLUTEN FEED AND HAY

Gluten feed combined with hay constitutes a very satisfactory basal ration for the study of materials that can not be successfully fed unless mixed with some other concentrate. In the first of the two trials, results of which are recorded in Table XXII, it was fed as a basal ration for corncobs. The second trial was included in a later series because of the poor results obtained for the gluten feed in the first. The ration fed consisted of 8.5 kilograms hay and 1.5 kilograms gluten feed.

TABLE XXII.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pound	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	IV	5	54.28	40.29	62.28	48.25	59.51	11.41	84.02	41.71
Chub	IV	5	54.89	38.34	60.94	49.04	60.74	9.59	85.31	42.88
Joe	V	3	49.98	24.51	69.29	42.30	55.71	None.	84.47	41.83
Chub	V	3	48.37	28.85	66.89	39.24	54.45	None.	80.73	38.49
Average			51.88	(a)	64.85	44.71	57.60	(a)	83.63	41.23

a Not averaged.

The results for the combined ration are reasonably uniform. When an attempt was made to calculate the digestibility and energy values for the gluten feed, by deducting the amount of hay digested, the data for the gluten feed itself seemed so unsatisfactory that the results are not published.

CORNCOBS, GLUTEN FEED, AND HAY

Corncobs were added to a basal ration of gluten feed and hay in order to determine their digestibility and energy values, the ration fed being 8 kilograms hay, 1.5 kilograms gluten feed, and 1.5 kilograms corncobs (Table XXIII).

TABLE XXIII.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	IV	6	51.33	29.12	60.81	43.13	57.79	None.	78.08	36.53
Chub	IV	6	51.52	32.19	57.72	43.70	58.19	None.	78.94	37.31
Average			51.43	30.66	59.27	43.42	57.99	None.	78.51	36.92

The data for the total rations are quite satisfactory, showing that each horse digested them equally well.

CORNCOBS

TABLE XXIV.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	IV	6	24.38	None.	32.71	2.46	44.01	None.	34.47	None.
Chub	IV	6	25.91	None.	None.	6.97	46.86	None.	32.14	None.
Average			25.15	None.	(a)	(a)	45.44	None.	33.31	None.

a Not averaged.

The horses were able to digest 25 per cent of the cobs, and this material evidently was the extractive or carbonaceous matter. Fiber (of which the cobs contained 30 per cent) was attacked very little if any, which evidently was due to its chemical structure. The energy expended in digesting the cobs rendered the net-energy value a minus quantity. The corn and cob may be ground together and fed; the latter comprises some 16 per cent of the ear, and can serve as a distributer of the grain, but can not be considered as furnishing the horse any real food (Table XXIV).

Summarizing the results with corn and its products:

Whole corn and corn meal were about equally utilized and contain, respectively, 113 and 117 therms of net energy per 100 pounds.

The results with gluten feed were so unsatisfactory that they were discarded. It can be assumed, however, that gluten feed contains about the same amount of energy per 100 pounds as does the corn from which it was made.

The results with corn bran were not satisfactory, but they indicated that it has considerable energy value, probably double that found in wheat bran.

Corncobs are of no energy value to horses.

COTTONSEED MEAL

Two lots of cottonseed meal were fed, the first in Series IV, with hay and wheat bran as the basal ration, the second in Series V with hay and oats.

The composition of the two lots is shown in Table XXV.

TABLE XXV.—*Composition of cottonseed meal*

Lot	Water as fed	Dry-matter basis					
		Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
I	7.62	7.10	37.51	19.69	28.04	7.66	224.53
II	8.76	6.68	41.27	12.79	31.22	8.01	225.44

The analyses show the first lot to be the ordinary "good" grade of meal, while the second lot would be rated "choice." The fiber in Lot I is unusually high, but is an average of six closely agreeing determinations, so the figure is not questioned.

COTTONSEED MEAL, WHEAT BRAN, AND HAY

In Series IV, period 3, the total ration consisted of 8.5 kilograms of hay, 1.5 kilograms of wheat bran, and 1.5 kilograms of cottonseed meal. In Series V, period 6, it consisted of 8.5 kilograms of hay, 1.5 kilograms of oats, and 1.5 kilograms of cottonseed meal. The horses digested and utilized the total ration in a fairly uniform manner. The results for the total ration are given in Table XXVI, and for cottonseed meal in Table XXVII.

TABLE XXVI.—*Compositon*

I. COTTONSEED MEAL, WHEAT BRAN, AND HAY

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	IV	3	54.00	29.16	68.56	42.99	60.77	34.34	84.95	43.00
Chub	IV	3	51.97	28.27	67.13	42.26	57.99	29.36	81.35	39.72
Average			52.98	28.72	67.85	42.63	59.38	31.85	83.15	41.36

II. COTTONSEED MEAL, OATS, AND HAY

Joe	V	6	47.34	25.00	70.19	38.02	49.65	40.03	80.71	39.39
Chub	V	6	48.32	29.24	68.99	37.85	51.93	42.05	83.66	42.08
Average			47.83	27.12	69.59	37.44	50.79	41.04	82.19	40.74

TABLE XXVII.—*Cottonseed meal*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	IV	3	60.51	51.07	83.95	23.03	70.52	89.80	101.96	61.39
Chub	IV	3	71.36	67.64	88.61	64.66	57.86	102.10	130.62	87.41
Joe	V	6	62.28	77.35	86.73	38.35	35.60	86.91	103.39	72.64
Chub	V	6	69.48	106.22	83.76	19.29	61.62	93.25	138.35	104.42

Strictly, the results for the two lots can not be compared, for the reason that the first lot was noticeably lower in protein and higher in fiber than the second lot. Joe continued his inability to handle the feed to as good advantage as Chub. The data show that the horses digested the protein quite well and as completely

as do ruminants. The fiber was much less fully utilized, but on the whole the coefficients were apparently equal to the coefficients for bovines. The digestibility of the extract matter varied noticeably, and this material was less completely utilized than it is in the case of the ruminant. While the fat coefficients varied, it is evident that the horses were able to make almost complete use of the fat.

The net-energy values likewise varied, due in part to the poor digestion of the horse Joe. It is clear, however, that the meal with the high percentage of fiber yielded less energy than that with the smaller amount. It is hardly fair to average the results obtained with the two horses, although they show 74 and 88 therms per 100 pounds, respectively, for the two different lots of meal. The data obtained for Chub are probably more reliable than those for Joe.

HAY

Hay was fed alone as a basal ration in 8 different experiments. In 2 of these the urine was not collected, so energy values are not available for them. Of the 6 lots for which the data are complete, 5 were from coarse grasses (largely timothy), and the other one was from fine grasses (Kentucky bluegrass predominating). All the hay fed was grown on the experiment station farm. Table XXVIII shows the composition of the different lots.

TABLE XXVIII.—*Composition of the hay*

Series	Period	Water as fed	Dry-matter basis					
			Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
II	1	15.13	4.86	5.89	34.84	52.08	2.33	201.40
II	8	10.00	5.11	7.21	33.63	52.03	2.02	200.49
III	1	11.88	3.83	4.39	32.81	56.80	2.17	193.23
IV	1	9.50	3.90	6.26	31.97	55.08	2.79	203.21
V	1	9.38	7.71	8.45	34.82	47.25	1.77	197.77
Average		11.18	5.08	6.44	33.61	52.65	2.22	199.22
VI(fine)	7	12.00	5.40	8.75	32.22	50.82	2.81	202.76

The greatest variations are in the protein and ash, due probably to difference in stage of maturity at time of cutting. The values for digestibility and energy appear in Table XXIX. The daily ration was 10 kilograms hay in three experiments and 10.5 kilograms in the other three.

TABLE XXIX.—*Digestion coefficients and energy values*

COARSE HAY

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	1	39.89	20.11	44.89	32.11	47.64	11.78	64.88	17.16
Tom	II	1	43.46	26.36	39.72	39.03	49.78	13.62	68.70	20.64
Joe	II	8	46.65	26.09	49.47	45.48	51.19	None.	75.22	28.03
Tom	II	8	46.78	26.06	47.44	45.78	51.37	None.	75.49	28.27
Joe	III	1	49.00	29.56	34.25	41.56	57.38	6.46	75.72	29.47
Tom	III	1	50.67	34.57	26.85	43.88	59.14	8.39	76.51	30.19
Joe	IV	1	54.17	40.42	48.38	47.77	61.52	14.42	84.66	38.61
Chub	IV	1	53.86	43.92	45.60	46.15	61.89	15.99	83.98	37.99
Joe	V	1	42.25	19.48	55.51	42.03	45.79	None.	67.06	19.17
Chub	V	1	41.82	21.90	52.84	41.43	45.61	None.	65.21	17.49
Average			46.86	28.85	44.50	42.52	53.12	(a)	73.74	26.70
FINE HAY										
Joe	IV	7	53.07	31.25	61.27	48.76	58.89	13.65	86.21	39.72
Chub	IV	7	48.14	25.58	53.77	45.95	53.50	2.19	72.26	27.03
Average			50.61	28.42	57.52	47.36	56.20	(a)	79.24	33.38
Timothy hay, average of 72 experiments with sheep			55.00	39.00	47.00	51.00	62.00	50.00	(b)	(b)

(a) Not averaged. (b) Not determined.

A study of the analysis and the results of the digestion and energy tests shows clearly that the higher the percentage of fiber the lower the metabolizable and net energy value. Thus, the hay fed in Series II, period 1, had 34.84 per cent of fiber; its metabolizable energy averaged 66.79, and its net-energy value averaged 18.9 therms per 100 pounds. The hay fed in Series V, period 1, contained substantially the same percentage of fiber, and averaged 66.13 therms of metabolizable and 18.33 therms of net energy per 100 pounds. The hay fed in Series IV, period 1, contained the lowest amount of fiber, and its fiber content was quite close to that of the fine hay fed in Series IV, period 7, namely, 32 per cent; the metabolizable energy was 84.32 and 79.24 therms, respectively, and the net-energy values of the hays in these two periods were 38.30 and 33.37 therms per 100 pounds, respectively. In case of the fine hay (Series IV, period 7) Chub did not digest as well as Joe, which explains its apparent lower energy value. The hay in Series II, period 8, and Series III, period 1, averaged 33.22 per cent fiber; the metabolizable energy was 75.35 and 76.11 therms, respectively, and the respective net-energy values were 28.15 and 29.83, figures midway between the low and the high net-energy values for the other lots. These results confirm the writers' hitherto accepted understanding, that stage of growth has a pronounced influence upon the nutritive value of hay—the more advanced the growth the higher the fiber content is likely to be and the less the net-energy value. The results also indicate that stage of growth is likely to be fully as important as variety in furnishing energy. One can not say that timothy or redtop, when fed to the

horse, contains 25 or 30 or 35 therms of energy per 100 pounds, because the earliness or lateness of cutting is bound to have a pronounced influence. On the basis of the writers' results, hay with 35 per cent of fiber is not likely to furnish more than 20 therms, while hay with 32 per cent fiber may furnish 34 or more therms of net energy per 100 pounds. It would be interesting to still further study this particular problem.

LINSEED MEAL

The composition of the two lots of linseed meal used is shown in Table XXX.

TABLE XXX.—*Composition of linseed meal*

Lot	Water as fed	Dry-matter basis					
		Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
I	10.44	5.14	38.78	8.95	40.98	6.15	205.03
II	10.17	6.63	34.55	8.55	42.87	7.40	214.55

It is quite evident that the oil had not been as completely extracted from Lot II as from Lot 1, this accounting for the somewhat higher fat percentage and calorific value for Lot II. The linseed meal was added to two distinct basal rations, namely, hay and wheat bran, and hay and oats. The digestion and energy results of the total ration are given in Table XXXI. The ration fed was 8.5 kilograms hay; 1.5 kilograms wheat bran, and 1.5 kilograms linseed meal.

TABLE XXXI.—*Linseed meal, wheat bran, and hay*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	IV	4	53.17	30.46	71.83	42.26	58.78	20.62	88.84	48.14
Chub	IV	4	51.71	32.30	68.63	38.18	58.78	19.14	85.06	44.61
Average			52.44	31.38	70.23	40.22	58.78	19.88	86.95	46.38
Cottonseed, bran, and hay (for comparison)			52.98	28.72	67.85	42.63	59.38	31.85	83.15	41.36

In Table XXXII are shown the results when 1.5 kilograms oats were fed instead of 1.5 kilograms wheat bran as shown in the previous table.

TABLE XXXII.—*Linseed meal, oats, and hay*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	V	7	46.53	27.76	66.36	35.11	51.55	20.02	77.78	38.36
Chub	V	7	43.71	25.37	64.27	29.98	50.05	14.66	74.53	35.40
Average			45.12	26.56	65.32	32.55	50.80	17.34	76.16	36.88
Cottonseed, oats, and hay (for comparison)			47.83	27.12	69.59	37.44	50.79	41.04	82.19	40.74

The combination of linseed meal, oats, and hay showed a lesser degree of digestibility and energy value than did the linseed meal, bran, and hay ration. However, the results obtained with the two horses in each trial are as uniform as could be expected.

TABLE XXXIII.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	IV	4	54.27	71.54	92.34	None.	48.07	38.80	132.13	101.15
Chub	IV	4	69.77	116.97	93.01	None.	65.67	68.17	160.05	125.84
Joe	V	7	56.59	101.22	79.12	None.	55.95	24.12	81.87	65.79
Chub	V	7	[a] 35.59	83.88	73.41	None.	42.47	7.91	70.92	55.74
Average			60.21	93.40	84.47	None.	53.04	[b]	[b]	[b]
Cottonseed meal (for comparison)			65.91	[b]	85.76	None.	63.33	93.02	118.58	81.47

[a] Omitted from the average. [b] Not averaged.

The results given in Table XXXIII are quite unsatisfactory. A careful study of all the data fails to locate any particular cause for the variation. The protein coefficients indicate a high degree of digestibility, and it can be assumed that linseed meal should be fully as well utilized by horses as was the cottonseed meal.

OATS

Oats are generally regarded as being the food par excellence for horses, and because of the prevalence of this idea they are apt to be high-priced and at times uneconomical. They were fed in combination with hay to determine their digestibility and energy values, and the combination was utilized as a basal ration for a similar study of other concentrates. Their composition, as fed was water 10.97 per cent; and dry matter 89.03 per cent, of which (considering the dry matter as 100 per cent) 3.35 per cent was ash, 13.38 per cent protein, 10.39 per cent fiber, 67.56 per cent nitrogen-free extract, and fat 5.32 per cent. The calorific value was 207.75 therms per 100 pounds. The ration consisted of 8.5 kilograms hay and 1.5 kilograms oats (Table XXXIV).

TABLE XXXIV.—*Digestion coefficients and energy values*

OATS AND HAY

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	V	4	44.38	12.19	57.88	38.15	50.94	18.71	77.15	34.17
Chub	V	4	45.32	19.47	59.40	38.80	51.26	17.35	75.08	32.30
Average			44.85	15.83	58.64	38.48	51.10	18.03	76.12	33.24

OATS

Joe	V	4	57.95		71.69	None.	71.45	59.32	134.86	119.88
Chub	V	4	64.19	0.98	78.48	None.	72.97	54.78	131.22	116.51
Average			61.07	(*)	75.09	None.	72.21	57.05	133.04	118.20
Oats fed to bovines			70.00		77.00	35.00	80.00	89.00		
Corn (for comparison)			74.49	(*)	61.63	None.	85.26	50.56	131.56	112.54

* Not averaged.

The results for the combined rations (Table XXXIV) were all that could be desired, the coefficients and energy values being quite uniform. The data obtained for the coefficients and energy values for the oats themselves are also satisfactory, only comparatively small differences being noted.

The horses did not seem to digest the fiber, nor to digest the fat or extract matter as well as ruminants do, but the protein seems to have been as fully utilized. Corn, as a whole, is more completely digested than oats; but the oats in the present experiment, for some unexplainable reason, apparently yielded more net energy than corn. Such data show that other experiments would be worth while, in order to ascertain definitely the comparative values of these two grains for horses.

OAT FEED

This material is a by-product of oatmeal manufacture, consisting of the reground hulls plus the middlings and dust from the first milling. Its value as a feed for different classes of farm stock was studied by this station some years ago, and a report of the investigation was published in bulletin form (*8*).

Its composition was water 9.53 per cent and dry matter 90.47 per cent, of which (regarding all the dry matter as 100 per cent) 4.96 per cent was ash, 5.85 per cent protein, 26.72 per cent fiber, 58.98 per cent nitrogen-free extract, and 2.49 per cent fat. The calorific value was 199.13 therms per 100 pounds. Its digestibility and energy values are presented in Table XXXV, the ration fed being 8 kilograms hay and 2.5 kilograms of oat feed.

TABLE XXXV.—*Digestion coefficients and energy values*

OAT FEED AND HAY

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	III	5	48.32	27.27	39.92	45.37	53.37	17.37	80.50	35.73
Tom	III	5	49.17	27.56	38.82	46.16	54.15	26.60	81.11	36.28
Average			48.75	27.42	39.37	45.77	53.76	21.99	80.81	36.01

OAT FEED

Joe	III	5	42.98	17.23	60.33	54.66	39.14	44.03	95.66	55.59
Tom	III	5	46.55	18.14	56.71	58.40	42.31	76.99	95.71	55.60
Average			44.77	17.68	58.52	56.48	40.73	60.51	95.69	55.60

The uniformity of the data for both the oat feed and hay and for the oat feed itself are quite remarkable. They show the fiber in the oat feed to be some 56 per cent digestible, while the fiber in the ground oats was not digested at all. This apparent contradiction must be due largely to the relatively small percentage of fiber in the ground oats as compared with that in the oat feed. The writer's experience also has made it seem that fiber especially may be more fully attacked in the digestive tract at some times than at others. Again, it hardly seems possible to the writer that oat feed, containing 26 per cent of fiber and composed of substantially 80 per cent oat hulls and 20 per cent of fine middlings, can contain 56 therms of net energy, or fully one-half as many as corn meal. (See also the results with oat hulls.) The data are presented as obtained, and it is hoped that it will be possible to make further study of this material, and also of the oats themselves. It can be said, tentatively, that oat feed of the character described here should be at least fully equal in feeding value to a good quality of hay.

OAT HULLS

Thousands of tons of oat hulls are produced annually by the oatmeal manufacturers. Most of this material is mixed with the oat middlings and dust and sold as "oat feed." Within the past few years considerable work has been carried on, both in this country and in Germany, in attempts to improve by various processes the nutritive value of this and other fibrous materials. In this country the Massachusetts station has done the most work (*1*) on the problem.

The hulls were fed with hay and dried brewers' grains as a basal ration. Their composition was as follows: Water 8.57 per cent, and dry matter 91.43 per cent, 6.59 per cent of the dry matter being ash, 2.52 per cent protein, fiber 33.04 per cent, nitrogen-free extract 56.83 per cent, and fat 1.02 per cent. Calorific value, 197.32 therms per 100 pounds. The hulls consisted principally of fiber and nitrogen-free extract, and these are made up largely of pentosans, cellulose, and lignin, there being very little readily soluble carbohydrate present. The results of the experiment are given in Table XXXVI, the ration fed being 8 kilograms hay, 2.5 kilograms brewers' grains, 2 kilograms oat hulls.

TABLE XXXVI.—*Digestion coefficients and energy values*

OAT HULLS, DRIED BREWERS' GRAINS, AND HAY

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	III	4	45.88	27.58	62.79	38.56	49.16	30.67	78.66	37.29
Tom	III	4	45.24	26.85	61.99	36.22	49.37	31.33	78.61	37.24
Average			45.56	27.22	62.39	37.39	49.27	31.00	78.64	37.27
Brewers' grains and hay (for comparison)			48.06	25.55	62.99	40.44	52.09	24.89	99.47	56.90
OAT HULLS										
Joe	III	4	24.36	35.68	122.76	27.86	9.75	76.46	None.	None.
Tom	III	4	20.39	32.66	104.80	15.30	11.00	88.42	None.	None.
Average			22.38	34.17	113.78	(a)	10.38	82.44	None.	None.

a Not averaged.

The digestibility and energy value of the total ration obtained were very uniform. The addition of hulls to the basal ration of hay and brewers' grains reduced the energy value one-third, that is, from 56.90 for the hay and brewers' grains to 37.27 for the hay, brewers' grains, and oat hulls.

While the results of the digestibility of the oat hulls themselves were concordant with the two horses, the coefficients are low, showing that scarcely one-fourth of the material was utilized. The fiber in the hulls was poorly digested, and as a result of the several trials with the oats, the oat feed, and the hulls, it can be assumed that horses are not able to digest the fiber to any appreciable extent. By the time the hulls were digested so much energy had been required in the process that none was left for production, which explains the negative net-energy value.

WHEAT BRAN

Wheat bran combined with hay was fed extensively throughout this entire investigation, in some cases as a component of a basal ration for other feeds, and in others to measure the value of the bran as a horse feed. The composition of the several lots of bran is given in Table XXXVII.

TABLE XXXVII.—*Composition of wheat bran*

Lot	Water as fed	Dry-matter basis					
		Ash	Protein	Fiber	N-free extract	Fat	Calorific value per 100 pounds
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Therms*
I	11.70	7.10	17.04	10.57	60.58	4.71	190.97
II	10.78	6.87	15.83	11.29	61.02	4.99	203.67
III	12.36	7.49	17.47	10.53	59.31	5.20	208.20
IV	12.13	7.54	16.80	11.40	58.53	5.73	207.75

The results of the numerous trials are summarized in Table XXXVIII.

TABLE XXXVIII.—*Digestion coefficients and energy values*

WHEAT BRAN AND HAY

Horse	Series	Period	Digestion coefficients (per cent)						Energy values per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Ration fed: 8 kilograms hay, 2 kilograms bran										
Joe	II	3	41.31	19.21	57.52	35.39	46.18	None.	63.73	22.25
Tom	II	3	45.50	23.57	59.15	39.86	50.33	9.01	71.11	28.96
Ration fed: 8 kilograms hay, 2.5 kilograms bran										
Joe	III	2	51.56	33.00	61.61	38.39	59.55	18.10	85.71	45.49
Tom	III	2	45.90	26.41	55.37	30.73	54.94	13.31	73.55	34.43
Ration fed: 8.5 kilograms hay, 1.5 kilograms bran										
Joe	IV	2	52.73	23.78	56.86	45.48	60.30	15.41	82.35	40.19
Chub	IV	2	48.73	19.34	50.84	40.41	57.55	4.47	73.82	32.43
Ration fed: 8.5 kilograms hay, 1.5 kilograms bran										
Joe	V	2	43.25	14.46	61.13	35.50	49.49	23.37	70.77	29.17
Chub	V	2	44.39	19.96	60.38	35.97	50.88	22.92	71.73	30.04
Ration fed: 1.5 kilograms bran, 8.5 kilograms hay, 1.5 kilograms oats										
Joe	V	5	44.01	14.99	54.74	37.80	50.41	16.27	74.47	34.24
Chub	V	5	45.54	19.64	56.15	37.78	52.37	18.20	76.32	35.93
Average			44.78	17.32	55.45	37.79	51.39	17.24	75.40	35.09

These series can not be compared one with the other, because not only were different amounts of hay and bran fed but in the several series the hay and also the bran were not of the same lot.

The results in each series are not as concordant as one could wish. It is evident that the horses had trouble in digesting the bran, for when hay was fed by itself both the digestion coefficients and net-energy values varied but little in each series. The most uniform results with the hay and bran were obtained in Series V, period 2. The results with the hay, oats, and bran showed uniformity.

TABLE XXXIX.—*Digestion coefficients and energy values*

Horse	Series	Period	Digestion coefficients (per cent)						Energy value per 100 pounds	
			Dry matter	Ash	Protein	Fiber	N-free extract	Fat	Metabolizable energy	Net energy
									Therms	*Therms*
Joe	II	3	46.53	16.77	80.48	79.57	*40.16	None.	59.15	42.54
Tom	II	3	55.47	16.10	94.26	51.06	51.40	1.02	80.70	62.14
Joe	III	2	56.53	35.00	91.07	None.	64.18	32.49	*117.69	*96.77
Tom	III	2	*32.78	15.33	78.84	None.	*45.78	21.47	64.08	48.03
Joe	IV	2	45.33	None.	76.87	18.54	51.10	16.60	68.94	49.39
Chub	IV	2	*18.11	None.	*58.63	None.	*33.51	None.	*14.78	*.14
Joe	V	2	50.33	None.	81.59	None.	*66.25	83.16	*91.85	*85.97
Chub	V	2	57.99	14.48	78.66	None.	74.34	81.54	*108.75	*101.34
Joe	V	5	*37.46	9.45	*41.07	34.22	*46.90	10.54	*56.62	*34.74
Chub	V	5	49.17	39.52	*47.02	33.87	60.53	18.87	84.54	60.06
Average			51.62	(?)	83.11	(?)	61.31	(?)	71.50	52.44
Average for bovines			66.00	31.00	77.00	31.00	72.00	68.00		53.00

* Omitted from the average.

The coefficients and energy values in Table XXXIX were determined in all cases by deducting the amounts of hay or hay and oats digested and metabolized from the amounts digested and metabolized in the total rations, the remainder being the wheat bran digested and metabolized. Comparatively slight differences in the remainder are likely to make rather noticeable differences in the coefficients and net-energy values. It is clear, however, that the horses did not find wheat bran easy to digest, as the variations in the different trials make clear. In the cases of the dry matter, protein, and nitrogen-free extract the results have been averaged after eliminating those which appear the most improbable. It is doubtful whether the horses were able to make much use of the fiber, and as a rule they were not able to digest the fat as well as ruminants. When it comes to net-energy value the problem is even more difficult. The extreme results have been eliminated and the other figures averaged, the result being a tentative net-energy value of 52.6 therms per 100 pounds. It is probable that this result is not far from correct. Armsby's estimated figure for ruminants is 53. Most of the digestion coefficients for ruminants are above those for horses, as the appended average shows. The writers conclude that wheat bran is not to be recommended as a source of nutrition for horses, but it may be fed to advantage in limited amounts because of its gentle laxative effect.

CORRELATION DATA

In Table XL are shown some correlations between crude-fiber content, total digestible nutrients, and net energy.

TABLE XL.—*Correlation between crude-fiber content, total digestible nutrients, and net energy in the different feeds*

[Feeds arranged in order of merit]

Order of merit	Percentage of fiber, arranged on basis of minimum fiber content		Digestible dry matter, arranged on basis of total digestible nutrients		Net energy, in therms, arranged on basis of net energy value	
First	Corn meal	2.59	Ground barley	77.70	Ground barley	150.20
Second	Shelled corn	3.03	Corn bran	76.19	Brewers' grains	140.84
Third	Ground barley	5.98	Shelled corn	74.49	Oats	118.20
Fourth	Gluten feed	6.66	Gluten feed	73.38	Corn meal	116.75
Fifth	Linseed meal	8.75	Corn meal	72.33	Gluten feed	(?)
Sixth	Oats	10.39	Cottonseed meal	65.91	Shelled corn	112.54
Seventh	Wheat bran	11.04	Oats	61.07	Corn bran	100.84
Eighth	Corn bran	12.15	Linseed meal	60.21	Linseed meal	87.13
Ninth	Brewers' grains	15.59	Wheat bran	51.68	Cottonseed meal	81.47
Tenth	Cottonseed meal	16.24	Alfalfa	51.05	Oat feed	55.60
Eleventh	Oat feed	26.72	Brewers' grains	51.01	Wheat bran	52.44
Twelfth	Corncobs	30.23	Hay (fine)	50.61	Hay (fine)	33.38
Thirteenth	Hay (fine)	32.22	Hay (coarse)	47.59	Hay (coarse)	26.70
Fourteenth	Oat hulls	33.04	Oat feed	44.77	Alfalfa	24.94
Fifteenth	Hay (coarse)	33.57	Corncobs	25.15	Corncobs	None.
Sixteenth	Alfalfa	35.05	Oat hulls	22.38	Oat hulls	None.

A careful study of the foregoing tables and of all the data on which they are based shows that the net energy is roughly inversely proportional to the amount of crude fiber present and directly proportional to the amount of digestible dry matter present. In other words, the higher the fiber content the less digestible matter and net energy the feed contains, and vice versa. Although high fiber and low net energy (or the reverse) are always associated, the nature of the fiber varies the relation somewhat. For example, the fiber in hay does not seem to be nearly so resistant to digestive action as it is in some materials which are not any higher or as high in fiber. The horses digested on an average about 43 per cent of the crude fiber of the hay, but apparently made noticeably less use of that contained in oats and wheat bran; on the other hand, digestibility may be influenced somewhat by the relative amounts of the different ingredients contained in the feed.

A relatively low percentage of any proximate constituent is often accompanied by a correspondingly low or even by a negative digestion coefficient. This may be only apparent, due to imperfections of the method employed to ascertain digestibility, or it may be due to a selective action on the part of the digestive tract, those constituents of the feed which are most abundant and which are characteristic of it being most completely digested, and vice versa. Such selective action is of course purely involuntary, and is explainable on a physicochemical basis, being governed by the law of mass action. It is probable also that when any proximate constituent (e. g., fat) is present only in small amounts it is less readily accessible to the digestive juices than it would be if it were a predominating constituent of a feed or ration.[9] All things considered, the amount of digestible dry matter is probably a better index of the net-energy value than is the crude-fiber content, although both should be considered.

[9] The low digestibility of protein contained in feeds in small amounts is due to the presence of metabolic products in the feces.

PERCENTAGE ENERGY EFFICIENCY OF FEEDS FOR HORSES

It is interesting to compare the gross energy values of the different feeds with their net energy values and to note the percentages of utilization. This has been done in Table XLI.

TABLE XLI

[Therms per 100 pounds]

Name of feed	Gross energy	Net energy	Percentage efficiency	Name of feed	Gross energy	Net energy	Percentage efficiency
Alfalfa	190.97	14.11	7.39	Hay (coarse) contd.	197.77	18.33	9.27
	197.32	35.73	18.11	Hay (fine)	202.76	33.38	16.46
Average	194.15	24.92	12.75	Average for hay	199.81	27.82	13.91
Barley	200.94	150.20	74.75	Linseed meal	205.03		
Brewers' grains	229.52	60.39	26.31	Oats	207.75	118.20	56.90
	229.07	140.83	61.48	Oat feed	199.13	55.60	27.92
Corn (shelled)	199.58	112.54	56.39				
Corn (meal)	203.67	116.75	57.32	Wheat bran	190.97	52.34	27.41
Corn (bran)	203.21				203.67	*48.03	23.58
Cottonseed meal	224.53	74.40	33.14		208.20	*49.39	23.72
	225.44	88.53	39.27		207.75	*60.06	28.91
Hay (coarse)	201.40	18.90	9.38	Average for wheat bran	202.65	52.46	25.91
	200.49	28.15	14.04				
	193.23	29.83	15.44	Total averages	205.46	64.00	30.76
	203.21	38.30	18.85				

* One horse only.

The average total calorific value expressed in therms for all feeds tested was 205.46, with extremes of from 191 to 229, the latter figure being obtained from brewers' grains, which naturally contained considerable fat. The therms of total energy for most cattle feeds per 100 pounds of dry matter will not vary much from 200, excepting for those with a high fat percentage.

The percentage of net energy utilized varied widely, from zero in case of corncobs and oat hulls to 74.7 in case of ground barley.[10] Two samples of alfalfa showed from 7.4 to 18.1 per cent of net energy; 6 samples of hay from 9.4 to 18.8, with an average of 13.9 per cent, and 4 samples of wheat bran, with an average percentage utilization of 25.91. Armsby (*2*, *p. 661*), in Table 203, computes the percentage of net energy available in case of ruminants as varying between 5 and 24 per cent for roughages; for corn meal and hominy feed, 46 per cent; wheat bran, 29 per cent; beet molasses, 49 per cent, and starch, 43 per cent. The writers fail to find on record data of the percentage utilization of energy of individual feeds by horses. Zuntz and Hagemann (*2*) have shown that the net efficiency of rations varied widely, depending upon the work performed. Thus, in case of walking without a load, the average efficiency was 35 per cent, in different grades of ascent; without a load, from 33.7 to 36.2 per cent; and with a load, 22.7 per cent. Zuntz and Lehmann (*2*) have found that after maintenance requirements were satisfied the horse was able to make use of about 26 per cent of the remaining energy in the form of a definite kind of work (net efficiency of the horse).

[10] This net energy is believed to be too high. Corn meal shows 57.3 per cent of the net energy utilized. It is surprising what a small percentage of the energy the horse is able to utilize, especially in case of the coarse feeds and by-products which contain much fiber.

A COMPARISON OF THE DIRECT AND INDIRECT METHODS OF DETERMINING METABOLIZABLE AND NET ENERGY

The direct method is the one employed by the writers. It consists in actually determining the amount of metabolizable energy, by deducting from the total energy consumed the amounts excreted in the feces, urine, and methane.

The indirect method proposed by Zuntz and Hagemann (*10, 2, p. 675–676*) is computed by multiplying the pounds per hundred of digestible organic matter (previously accertained by an actual digestion experiment) by the factor 1.796, the results representing the metabolizable energy in therms per 100 pounds. This factor is based on several experiments with horses. The therms of net energy in either case are calculated by the formula described on page 573.

TABLE XLII.—*Average metabolizable and net energy*

Series	Period	Feeding stuff	Metabolizable		Net	
			Direct	Indirect	Direct	Indirect
I, II	5, 4	Alfalfa	75.86	86.67	24.94	36.75
III	6	Barley	163.91	133.67	150.20	144.45
II	5	Brewers' grains	90.81	79.91	60.40	53.42
III	3	Brewers' grains	171.90	86.99	140.84	61.01
II	7	Corn (shelled)	131.56	131.42	112.54	115.96
II	7	Corn (meal)	130.45	131.55	116.75	116.61
II	2	Corn (bran)	130.36	131.19	100.84	104.79
IV	6	Corncobs	33.31	45.16	None.	4.76
IV	3	Cottonseed meal	116.29	116.64	74.40	82.47
		Cottonseed meal	120.87	107.79	88.53	82.73
II, III, IV, V	1 to 8	Hay (coarse, average)	73.74	83.59	26.70	35.72
IV	4	Linseed meal	146.09	110.32	113.50	89.64
V	7	do	76.40	79.89	60.77	62.42
V	4	Oats	133.04	108.36	118.20	86.11
III	5	Oat feed	95.69	73.40	55.60	34.68
II, III, V	3, 2, 2, 5	Wheat bran	82.95	77.71	66.45	57.44

The condensed table shows that the results are not at all concordant. The coarse feeds (e. g., alfalfa and hay) have given higher results by the indirect method. In the case of corn, with little fiber, the energy values are quite uniform by both methods. Barley also, with little fiber, proved an exception. In case of cottonseed meal, the results with both methods are fairly uniform. The two results with linseed meal are at variance one with the other. Brewers' grains and oats have given higher results by the direct method.

In view of the fact that either method may give variable results, one is not justified in claiming positive superiority for either. Naturally the direct method should be given the preference.

NITROGEN BALANCES

The nitrogen balances of the horses were determined in all cases in the usual manner. Table XLIII summarizes the results:

TABLE XLIII.—*Nitrogen balances*

Horse	Series	Period	Nitrogen (grams)		
			Consumed	Excreted	Balance
Ration fed: 5 kilograms alfalfa, 5 kilograms hay					
Joe	I	5	151.07	144.51	+6.56
Tom	I	5	151.07	139.80	+11.27
Joe	II	4	142.77	141.77	+1.00
Tom	II	4	142.77	147.45	−4.68
Ration fed: 8.25 kilograms alfalfa, 6.6 kilograms corn, 1.65 kilograms oats (Kansas)					
Joe	I	3	141.35	269.71	−128.36
Tom	I	3	141.35	154.40	−13.05
Ration fed: 9 kilograms hay, 4.2 kilograms corn, 2.4 kilograms oats, 1.21 kilograms bran, 1.8 kilogram brewers' grains					
Joe	I	4	142.77	141.77	+1.00
Tom	I	4	142.77	147.45	−4.68
Ration fed: 2.5 kilograms barley, 8 kilograms hay					
Joe	III	6	100.31	92.43	+7.88
Tom	III	6	100.31	92.69	+7.62
Ration fed: 2.5 kilograms brewers' grains, 8 kilograms hay					
Joe	II	5	195.74	223.48	−27.74
Tom	II	5	195.74	206.19	−10.45
Joe	III	3	157.25	144.06	+13.19
Tom	III	3	157.25	136.19	+21.06
Ration fed: 2.5 kilograms corn (shelled), 8 kilograms hay					
Joe	II	7	111.92	111.37	+0.55
Tom	II	7	111.92	100.37	+11.55
Ration fed: 2.5 kilograms corn meal, 8 kilograms hay					
Joe	II	6	110.43	106.98	+3.45
Tom	II	6	109.41	104.46	+4.95
Ration fed: 2 kilograms corn bran, 8 kilograms hay					
Joe	II	2	89.21	107.19	−17.98
Tom	II	2	89.21	82.27	+6.94

TABLE XLIII.—*Nitrogen balances*—Continued

Ration fed: 1.5 kilograms gluten feed, 8.5 kilograms hay

Horse	Series	Period	Nitrogen (grams)		
			Consumed	Excreted	Balance
Joe	IV	5	140.71	127.14	+13.57
Chub	IV	5	140.71	128.24	+12.47
Joe	V	3	167.20	157.67	+9.53
Chub	V	3	165.98	152.47	+13.51
Ration fed: 1.5 kilograms corn cobs, 1.5 kilograms gluten feed, 8 kilograms hay					
Joe	IV	6	51.00	138.13	+12.87
Chub	IV	6	51.00	140.04	+10.96
Ration fed: 1.5 kilograms cottonseed meal, 1.5 [a] kilograms wheat bran, 8.5 kilograms hay					
Joe	IV	3	193.94	182.21	+11.73
Chub	IV	3	193.94	182.73	+11.21
Joe	V	6	223.83	215.19	+8.64
Chub	V	6	223.83	194.13	+29.70
Ration fed: 10 kilograms [b] hay					
Joe	II	1	79.78	93.76	−13.98
Tom	II	1	79.78	92.95	−13.17
Joe	II	8	103.50	101.78	+1.72
Tom	II	8	103.50	99.63	+3.87
Joe	III	1	64.77	75.53	−10.76
Tom	III	1	64.77	78.93	−14.16
Joe	IV	1	95.03	94.67	+.36
Chub	IV	1	95.03	88.69	+6.34
Joe	V	1	122.34	127.34	−5.00
Chub	V	1	122.34	124.02	−1.68
Ration fed: 10.5 kilograms fine hay					
Joe	IV	7	129.36	114.05	+15.31
Chub	V	7	129.36	125.71	+3.65
Ration fed: 1.5 kilograms linseed meal, 1.5 kilograms wheat bran, 8.5 kilograms hay					
Joe	IV	4	198.25	170.51	+27.76
Chub	IV	4	198.25	176.59	+21.64
Ration fed: 1.5 kilograms linseed meal, 1.5 kilograms oats, 8.5 kilograms hay					
Joe	V	7	203.51	200.44	+3.07
Chub	V	7	203.51	185.57	+17.94
Ration fed: 1.5 kilograms oats, 8.5 kilograms hay					
Joe	V	4	130.10	132.20	−2.10
Chub	V	4	129.53	128.76	+.77

[a] In series V, period 6, 1.5 kilograms oats in place of wheat bran.
[b] In series III, period 1, and series IV, period 1, 10.5 kilograms hay fed.

TABLE XLIII.—*Nitrogen balances*—Continued

Horse	Series	Period	Nitrogen (grams)		
			Consumed	Excreted	Balance
Ration fed: 2.5 kilograms oat feed, 8 kilograms hay					
Joe	III	5	70.01	75.15	−5.14
Tom	III	5	70.01	89.90	−19.89
Ration fed: 2 kilograms oat hulls, 2.5 kilograms dried brewers' grains, 8 kilograms hay					
Joe	III	4	165.48	138.46	+27.02
Tom	III	4	165.48	151.12	+14.36
Ration fed: 2 kilograms wheat bran, 8 kilograms hay					
Joe	II	3	136.21	139.59	−3.38
Tom	II	3	136.21	134.55	+1.66
Ration fed: 2.5 kilograms wheat bran, 8 kilograms hay					
Joe	III	2	110.69	101.54	+9.15
Tom	III	2	110.69	106.50	+4.19
Ration fed: 1.5 kilograms wheat bran, 8 kilograms hay					
Joe	IV	2	111.67	105.43	+6.24
Chub	IV	2	111.67	102.50	+9.17
Joe	V	2	137.30	87.83	+49.47
Chub	V	2	137.30	88.80	+48.50
Ration fed: 1.5 kilograms wheat bran, 1.5 kilograms oats, 8.5 kilograms hay					
Joe	V	5	149.15	155.65	−6.50
Chub	V	5	149.15	143.69	+5.46

The object was to feed a maintenance ration which would keep the horses in substantial weight equilibrium. It was not possible to maintain the nitrogen equilibrium because of the frequent changes in the character of the rations, some containing decidedly more nitrogen than others. Thus, in case of the basal hay rations, while the amount fed in all cases was about the same (10 to 10.5 kilograms daily), the nitrogen in the same varied considerably, the two lowest showing 64.77 and 79.78 grams, in which cases the horses had a minus equilibrium from 10 to 14 grams of nitrogen, indicating a probable deficiency of nitrogen.

A complete study of the summary indicates that the variations from equilibrium are not marked in the majority of cases and are mostly positive in character. Only one extreme case is observed, namely, a negative balance of 128.36 grams of nitrogen daily, when Joe was receiving the Kansas ration. This would indicate some temporary abnormal condition.

GENERAL SUMMARY AND CONCLUSIONS

The ultimate object of this investigation was the determination of digestibility and net-energy values of numerous common feeds suitable for horses.

Thirty-one metabolism experiments, with two horses in each, were carried on. From the results of these experiments, the digestibility, metabolizable energy, and net energy of 16 individual feeds were calculated.

The cereal grains and their high-grade products had a higher net-energy value than the strictly nitrogenous concentrates. Wheat bran, as a horse feed, gave results inferior to those of any other concentrate fed. Hay and alfalfa had about the same average net-energy value, but different samples varied widely, depending, evidently, on the stage of growth. Such materials as corncobs and oat hulls had no net-energy value.

The percentage net energy or production values varied from zero to 60 or more per cent, with an average of 32 per cent for all the feeds studied.

Net energy increases as crude-fiber content decreases, and is, as a rule, directly proportional to digestible dry matter. The net-energy value of any feed can be estimated approximately from these two values.

The character of the fiber influences its digestibility and the net-energy values. Thus, the fiber contained in corn bran has a higher energy value than that contained in oats, corncobs, or wheat bran.

The direct method of determining metabolizable energy is to be preferred to the indirect method suggested by Zuntz and Hagemann. The indirect method should be used only when it is not possible or convenient to make direct determinations.

The abundant constituents which characterize a feed or ration have, as a rule, an apparently higher digestibility than those present in minor amounts. This is due, at least in part, to imperfections of the method employed.

The nitrogen balances, with one exception, did not vary widely; and in most cases they were positive.

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